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NORMATIVE BILATERAL BRAINSTEM EVOKED RESPONSE DATA FOR A NAVAL AVIATION STUDENT POPULATION: GROUP STATISTICS

W. Carroll Hixson and James D. Mosko

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(10) W. Carroll Hixson and James D. Mosko

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Approved by

Ashton Graybiel, M.D.
Assistant for Scientific Programs

Released by

Captain R. E. Mitchell, MC, USN
Commanding Officer

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NAVAL AEROSPACE MEDICAL RESEARCH LABORATORY
NAVAL AIR STATION
PENSACOLA, FLORIDA 32508

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SUMMARY PAGE

THE PROBLEM

New measures of sensorineural performance are required which can be applied to the initial selection of naval aviation personnel and the medical management of fleet personnel during the course of their active careers (STO-PN; 11-D-6, Fitness Standards and Screening, July 1977: OPNAVMemo 098E/123-78, 23 October 1978; Subj: Aviation Biomedical Research Program Input to the Naval Aviation Plan).

FINDINGS

A biomedical instrumentation capability has been developed and exploratory research has been initiated to investigate the potential contributions of brainstem auditory evoked response technology to aviation medicine. Brainstem data based upon simultaneous ipsilateral and contralateral recordings have been collected and analysed for a selected population (age 20 to 24 years) of naval aviation students. An extensive set of statistical tables is provided for both the ipsilateral and contralateral data which establishes the normative range of brainstem responses for the study population. These tables include latency, transmission time, half-period, and peak-to-peak amplitude measurements for brainstem Waves I through VI. Timing and amplitude differences observed between the ipsilateral and contralateral brainstem recordings for certain of the waves are described in detail. A set of correlation matrices is included to describe the relationships that exist among both the brainstem waves and the brainstem measurement variables.

ACKNOWLEDGMENTS

The authors wish to thank Mr. Andrew N. Dennis, Jr., Bioenvironmental Engineering Division, for the many technical contributions he made to the project and to acknowledge the sustained effort he devoted to the collection of the brainstem data. Acknowledgment is also extended to Mr. John R. Bowman who, while serving as a special assistant to the commanding officer for systems analysis, developed special microcode software to expedite the multichannel averaging of the brainstem evoked response potentials.

INTRODUCTION

In the military flight environment, personnel are exposed to a variety of stressors (e.g., noise, vibration, turbulence, etc.) which can produce physiological reactions that degrade mission performance. Stressors combined with a heavy workload place a considerable burden on the physiological processes. Although the duration of the physiological effects caused by stressors generally is brief, long-term cumulative exposure occasionally can produce debilitating reactions that require some form of medical management. Since the medical threat to career personnel with long histories of exposure to such stressors is insidious in nature, aviation medicine has emphasized the need to monitor the physical health of personnel on a continuing basis.

The development of causal relationships between environmental stressors and degraded physical health or performance is limited by the aging process of career personnel. In effect, the aging process can be expected to produce physiological changes which might be ascribed incorrectly to the environmental stressors to which these same personnel were exposed. Physiological changes, whether due to aging or to the cumulative effects of environmental stressors, occur gradually and are difficult to detect with current standardized medical tests and techniques. In this context, exploratory research has been initiated to investigate the potential of brainstem auditory evoked response technology to serve both as a medical screening and management tool and as a sensitive means for the early detection of sensorineural changes that can occur as a result of either natural or premature aging.

The technology associated with measurement of the brainstem auditory evoked response was derived primarily from the electrocochleographic work of Sohmer and Feinmesser (27) and the vertex potential explorations of Jewett, Romano, and Williston (12). The method incorporates the detection of nanovolt-level electrophysiological signals at the vertex of the calvarium during the first 10 milliseconds or so following arrival of an auditory stimulus at the ear. Five to seven distinct cyclic waves in the signal provide a summated description of volume-conducted action potentials extending from the cochlea through the VIIIth nerve to the brainstem auditory centers (3,11,13,14). Relatively noise-free records are obtained by using either time- or frequency-domain signal-averaging techniques based on the sequential presentation of 1000 to 8000 transient auditory stimuli. In contradistinction to the frequency spectra of conventional EEG recordings which generally cover, at most, the 1-1000 Hz range, the brainstem recordings cover a frequency range extending from at least 100 Hz to over 2000 Hz.

Galambos and Hecox (9) and Davis (6) have outlined the noteworthy progress that has been made toward applying the brainstem auditory evoked response (BAER) measurement technique to a variety of clinical situations involving audiological disorders. Since the BAER can be recorded without any specific overt action or task required from the subject, it is of particular advantage when measures of auditory function are required of individuals incapable of making (or unwilling to make) conventional audiometric

responses as a result of such factors as age, mental disability, trauma, disease, or malingering. Sohmer et al. (28) have also shown that the BAER can also find diagnostic applications in nonorganic hearing loss, while Coats (4) has investigated its potential to identify retrocochlear auditory lesions. As represented by the work of Sohmer, Feinmesser, and Szabo (29), Starr and Achor (30), and of Starr and Hamilton (31), the BAER has also been of benefit in the diagnosis of a variety of neurological disorders, including demyelination and loss of circulation. In addition, the BAER and its variations are beginning to serve an important function in psychological and physiological acoustics as typified by the work of Bauer, Elmasian, and Galambos (1), Hecox, Squires, and Galambos (10), Picton and Hillyard (17), and Pratt and Sohmer (22).

If BAER testing techniques are to find application in the initial screening of new personnel and the sustained medical management of career personnel, data which will define the range of responses to be expected from a broad age-range population are required. As pointed out by Rowe (23), comparisons of BAER data available in the literature is made difficult by the many variations in stimulus techniques currently in use. Numerous dissimilarities exist in the exact method selected to record, time-average, identify, and measure the evoked potentials. Differences exist in the site selected for the active and ground electrodes, the recording bandwidth, the use of single or alternate polarity condensation and rarefaction acoustic stimuli, the rate of stimulation, and the number of responses used to construct the time-averaged BAER. Since each laboratory must select the measurement combination that best meets its research or clinical objectives, the direct quantitative comparison of brainstem data derived under different stimulus/response conditions necessarily will be limited. In effect, at this stage of BAER development, each measurement situation will require the collection of data to establish the normative ranges of responses produced by the test for a selected population.

This report is directed toward providing normative BAER data for a selected population of young (age 20-24 years) naval aviation students at the time of their initial entry into flight training. The measurement technique used for this preliminary evaluation is based on the monaural presentation of acoustic click stimuli and the simultaneous measurement of brainstem responses derived from the vertex and ipsilateral mastoid and from the vertex and contralateral mastoid. A relatively high stimulus rate was selected as a compromise between the number of individual brainstem waves that could be repeatedly measured and the overall duration of the test. Since career personnel routinely are exposed to a variety of clinical audiometric tests which can readily establish hearing thresholds, the current BAER test protocol does not utilize low-level or near threshold stimuli. Instead, attention is given to relatively high stimulus presentation levels which generally produce recordings where the majority of the individual brainstem waves can be quantitatively identified and their response characteristics analyzed with reference to the stimulus levels and with each other.

PROCEDURE

SUBJECTS

Thirty-five aviation students, both naval aviator and naval flight officer candidates, served as volunteer subjects for the study. Students were tested at the time of their initial entry into the flight training program and following a comprehensive flight physical examination that included audiometric testing. All subjects were between 20- to 24-years of age and exhibited hearing threshold levels within normal limits. Older students were not included since a long-term objective of the study is to utilize the BAER data derived from this relatively young population as a comparative reference for data to be collected from much older career personnel. The mean age of the group was 22.1 years. At least five subjects were included in each yearly age bracket.

MEASUREMENT INSTRUMENTATION

A simplified block diagram of the instrumentation system used to record the early components of the brainstem potentials evoked by repetitive acoustic click stimuli is shown in Figure 1. A digital clock, set to 21 Hz in

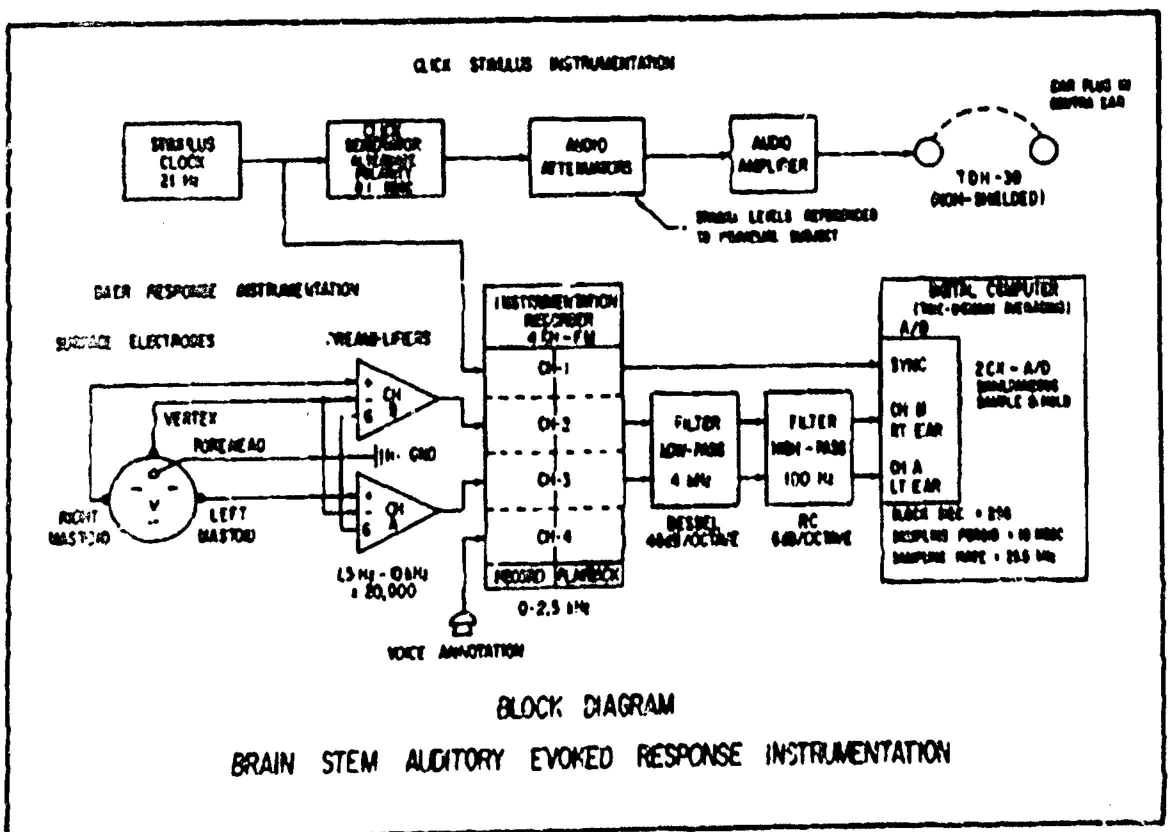


Figure 1

Block diagram of instrumentation system utilized to simultaneously record ipsilateral and contralateral brainstem evoked response potentials produced by monaural acoustic click stimuli presented at a 21-Hz repetition rate.

order not to be a direct subharmonic of the 60-Hz power line frequency, drove a balanced click generator which provided alternate polarity, 100 microsecond pulses. The clicks were routed through two cascade-wired 600-ohm attenuators (Hewlett-Packard Model 350-D). The input attenuator was used to establish the threshold for a given subject, and the output attenuator was used to set the click stimuli a given dB increment above threshold. The output attenuator drove a line amplifier (Spectra Sonics Model 110) that energized a single, 10-ohm TDH-39 earphone mounted in a MX-41AR ear cushion. Electromagnetic shielding of the earphone was not necessary since time-averaging of the responses to the alternate polarity clicks effectively canceled the electromagnetic artifacts produced by pulse-energizing the earphone drive coil. The resulting alternate condensation and rarefaction acoustic clicks had a similar canceling effect on the cochlear microphonic potentials which follow, in general, the polarity and shape of the click waveform.

The brainstem evoked response potentials were derived from surface electrodes located at the vertex of the skull, the mastoid prominence behind each ear, and the forehead of each subject. The ipsilateral signal, defined as the potential difference between the vertex electrode and the mastoid electrode behind the click-stimulated ear, was amplified by a differential-input preamplifier (Hewlett-Packard Model 8811A Bioelectric Preamplifier) with a frequency response extending from 1.5 Hz to 10 kHz and a gain of 20,000. A similar preamplifier was used to raise the level of the contralateral response derived from the same vertex lead and the opposite mastoid lead. The forehead electrode served as a common ground reference for the two preamplifiers. A four-channel cassette magnetic tape instrumentation recorder (Phillips Minilog 4; with FM record/reproduce electronics) was used to store the output from the two preamplifier channels. The frequency response of the tape recorder extended from dc through 2.5 kHz. The remaining two channels of the tape system were used to record a synchronizing pulse from the stimulus clock and voice annotation data describing the test conditions.

A 16-bit digital computer (Hewlett-Packard Model 5451B Fast Fourier Transform Analyzer) was used to construct time-averages of the ipsilaterally and contralaterally recorded evoked response signals. Before digitizing the two signals, the output of the tape recorder was passed through a low-pass Bessel filter (Rockland Systems Model 816; Bessel Card 06) with a cut-off frequency of 4 kHz and an attenuation rate of 48 dB/octave. This filter, which introduces a constant time delay of approximately 0.25 millisecond, was selected to minimize frequency-dependent phase or timing errors for the different brainstem waves. Since the frequency response of such a constant phase filter begins to fall off considerably before the 4-kHz cutoff frequency as compared to the response of a constant amplitude filter, the advantages of a fixed time-delay for this application are accomplished at the sacrifice of amplitude constancy over the response spectrum. The output of this filter was routed through a simple, single-section, high-pass RC network with a 100-Hz cutoff frequency to the input of the 12-bit analog-to-digital converter. A time period of 10 milliseconds was selected as the time-base for the averaging operations. Sample and hold circuitry simultaneously digitized the two brainstem recordings at a 25.5-kHz rate and

stored the resulting 10-millisecond sample for each channel in a 256 block record. Specialized software allowed the conversion and time-averaging processes to occur at the 21-Hz click stimulation rate. The software constructed three separate time averages for the 4000-click stimuli presented in each experimental run. One time-average was constructed for the first 2000 clicks, a second average for the following 2000 clicks, and a third for the total 4000 clicks. Each of the time averages was stored on disk for later recall and analysis.

SYSTEM CALIBRATION

The gain of each brainstem preamplifier was set to 20,000, using a 50-microvolt calibration signal applied to the differential input and an oscilloscope to monitor the resulting output. To document system calibration, the preamplifier output produced by the 50-microvolt calibration signal was always recorded on the lead section of the magnetic tape used to store the brainstem data associated with a given experimental run.

Calibration of the acoustic output of the TDH-39 earphone was accomplished by means of a 6-cm^3 coupler (Bruel and Kjaer Type 4152) which coupled the earphone to a one-inch condenser microphone (Bruel and Kjaer Type 4144). The sensitivity of the microphone was calibrated by both a pistonphone (Bruel and Kjaer Type 4220) which produced a 124-dB rms, 250-Hz tone and a sound level calibrator (General Radio Model GR-1562) which produced 114-dB rms tones at 125, 250, 500, 1000, and 2000 Hz.

Verification of attenuator calibration at a given stimulus level was accomplished by time-averaging 100 unidirectional acoustic clicks derived from the output of the coupler. The resulting improvement in signal-to-noise ratio allowed system linearity to be checked throughout the stimulus and threshold measurement ranges. The time-amplitude profile of a typical click signal produced by a TDH-39 earphone is shown at the left in Figure 2. The response of the same earphone in the frequency domain is shown at the right in Figure 2 in the form of an energy spectral density plot. The click energy distribution was relatively flat over the 100-6000 Hz spectrum with the exception of resonance peaks at approximately 3000 and 5400 Hz.

Each testing session involved the sequential presentation of three different click levels adjusted to be 40, 60, and 80 dB above the threshold at which each individual subject was able to detect the 21-Hz train of pulses. The overall noise background was such that the mean sensory threshold for the group was approximately 40 dB peak Lp relative to 20 μPa. Thus the 40, 60, and 80 dB sensation level (SL) stimuli reported in this study correspond to approximately 80, 100, and 120 dB peak Lp. The time-domain signal shown at the left in Figure 2 represents a 120 dB peak Lp click where the peak amplitude was measured between the first peak and the preceding baseline. The peak-equivalent Lp was approximately 3 dB greater.

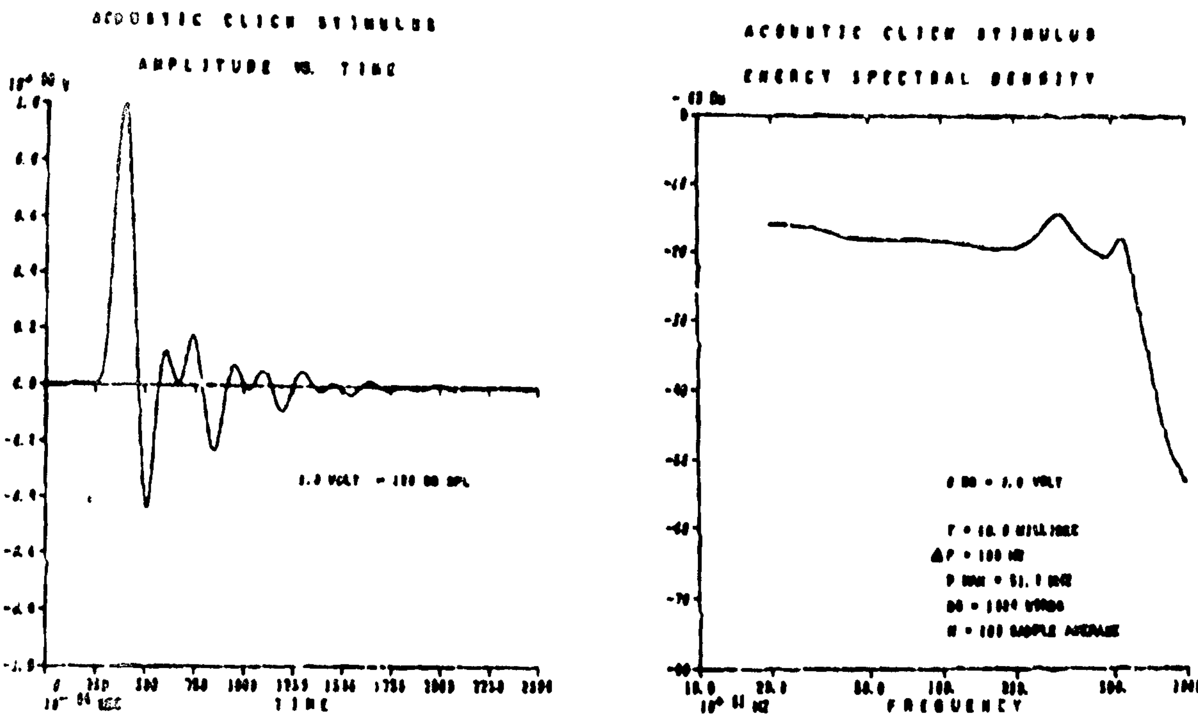


Figure 2

The amplitude-time profile of the acoustic click stimulus as produced by an unshielded 10-ohm TDH-39 headset and measured with an artificial ear microphone/headset coupler is shown at the left. The frequency-domain characteristics of the same acoustic click stimulus are shown at the right in the form of an energy spectral density plot. For this study, 40, 60, and 80 dB sensation level (SL) stimuli levels were used, which corresponded approximately to 80, 100, and 120 dB peak SPL.

EXPERIMENTAL METHOD

In applying the surface electrodes, the vertex, left and right mastoid prominences, and the forehead regions were lightly scrubbed with a mild detergent solution and with alcohol. A conductive electrode paste (Grass Instrument Type EC-2 Electrode Cream) was applied to conventional 5-mm diameter silver EEG electrodes backed by 2-cm square gauze pads which were pressed against the skull in the appropriate position and held in place for 10 to 15 seconds to allow adhesion. Interelectrode impedance was checked by means of a 30-Hz impedance meter (Grass Instruments Model EZM0) and maintained at 10,000 ohms or less.

Following electrode application, the subject reclined in a supine position on a small bed installed inside a dimly lighted, acoustic testing booth (Industrial Acoustics Model SP400). The subject shaped a plastic ear plug (Flint Products Silaflex Anti-Noise Ear Protector) and inserted it into his right ear. He positioned a headset such that the left earphone served as the stimulus source and right earphone as a dummy ear-covering. A measure was made of the left-ear sensory threshold level, bracketed by ascending and descending level stimuli, at which the subject could just detect the presence of the 21-Hz click train. The subject was then instructed to close

his eyes, keep his teeth separated, and try not to cough or swallow during the course of each stimulus presentation. Three 200-second sequences of clicks (each sequence involved approximately 4200 clicks and was separated by at least a one-minute rest interval) were presented at stimulus levels 40, 60, and 80 dB above the volitional left-ear threshold. Upon completion of these three sequences, the ear plug was transferred to the left ear, the headset reversed, and a threshold determination made for the right ear. The sequential presentations for right-ear stimuli adjusted to 40, 60, and 80 dB above the right-ear threshold then followed.

BRAINSTEM DATA ANALYSIS AND RELATED NOMENCLATURE

The magnetic tape records containing the ipsilateral and contralateral brainstem evoked responses were played into the digital computer to construct the desired time-averages. The results were stored on a disk for post-run analysis. Thirty-six disk records (each record consisted of 256 sequential words defining the amplitude/time profile of each averaged response) were required for each subject and contained the simultaneous analysis of the ipsilateral and contralateral responses of each ear to the 40, 60, and 80 dB SL stimuli. Each analysis involved a separate time-averaged record for the first 2000 clicks, the second 2000 clicks, and the total 4000 clicks.

The 36 disk records associated with a given subject were displayed simultaneously on a CRT terminal (Tektronix Model 4012) and a hard copy, single page plot was made of the results for inspection. In addition, the twelve, 4000-sample, time-averaged responses were individually recalled and displayed on the same terminal. The individual wave components were identified visually and, by means of an adjustable cursor, measurements made of the time incidence and absolute amplitude of each identified negative and positive waveform peak. The nomenclature used to identify the individual waves is shown in Figure 3, which presents the ipsilateral brainstem recordings obtained from six different subjects in response to stimuli presented at 80 dB SL. As indicated by the symbols positioned adjacent to each major peak in the top record, the wave identification notation follows the Roman Numeral I through VII convention of Jewett and Williston (13), with the additional condition that each individual wave number is followed by an N (negative polarity) or P(positive polarity) suffix to separately identify each of the two peaks generally found to be present in a given wave. It should be noted that the choice has been made to display the brainstem responses such that a <u>positive</u> potential at the <u>mastoid</u> relative to the vertex produces an upward or positive deflection on the record. (It is often convention to display the brainstem responses such that vertex positivity relative to the mastoids produces an upward deflection.) This arbitrary decision was made to facilitate the comparison of Wave I-N, the first component of the brainstem response, to the first component, generally identified as NI, of the electrocochleography response (8,20,24,41) using the same polarity convention.

Using the time and amplitude measures derived from the cursor analysis of the individual records as reference, statistical calculations were performed on four derived measurements--latency, transmission time, half-period, and peak-to-peak amplitude--for each individual brainstem wave

component. These measurements are identified in Figure 4 which displays the ipsilateral brainstem evoked response of a single subject in response to 4000 clicks presented at 80 dB SL. In this figure and in all figures which follow, the time at which the first peak of the click stimulus reaches the ear relative to time t=0 on the display time axis is defined as Ts. This delay, using the fast rise-time pulse produced by the 21-Hz clock used to produce the clicks as a zero reference, was estimated to be 0.468 millisecond and included components due to the finite rise-time of the sync pulse recorded on tape which triggered the analog-to-digital converter during the time-averaging operations; the acoustic delay of the click in reaching the ear (set equal to the delay measured with the artificial ear); and the

BRAINSTEM AUDITORY EVOKED RESPONSE DATA
NOTATION FOR IDENTIFICATION OF INDIVIDUAL WAVE COMPONENTS

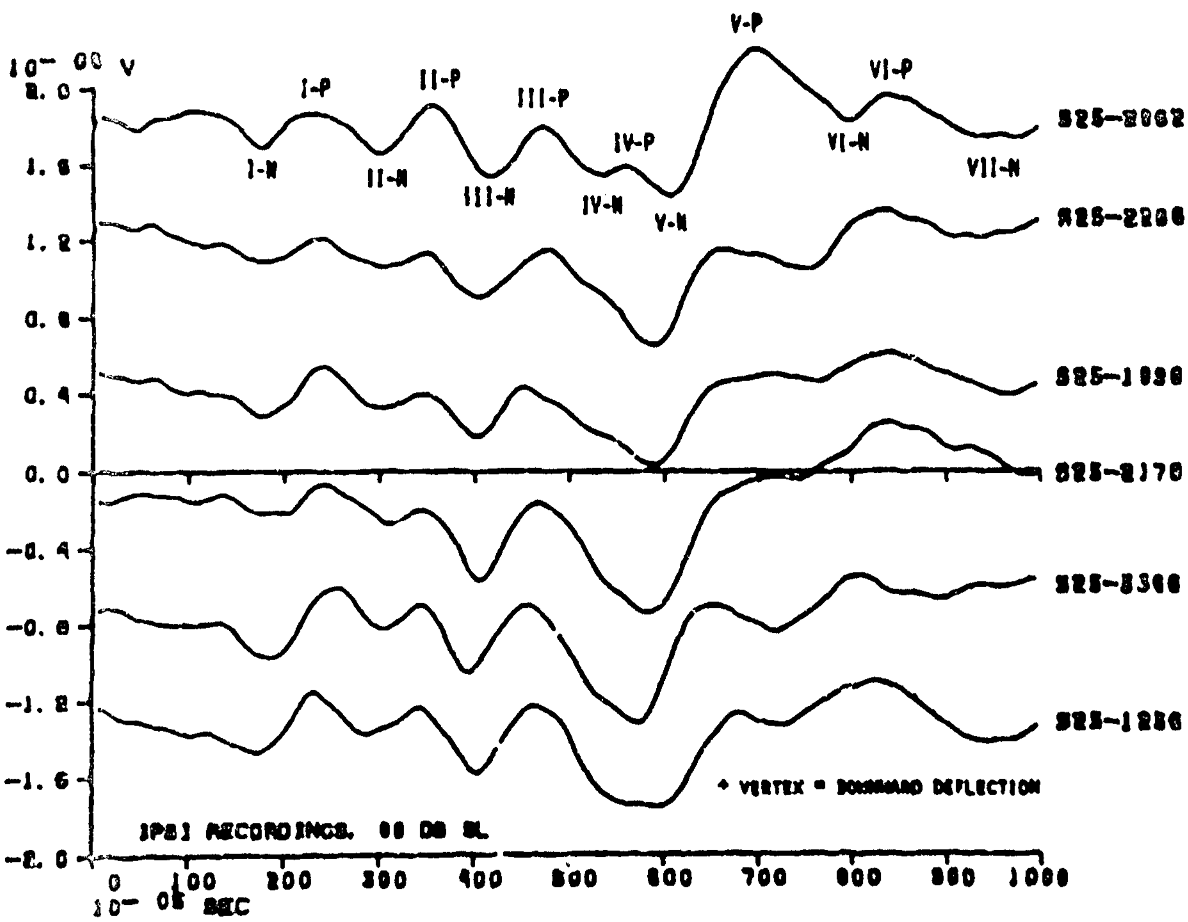


Figure 3

Ipsilateral brainstem evoked responses produced by 80 dB SL click stimuli (time-averaged response to 4000 clicks) for six different subjects. The notation follows the Roman numeral Wave I through Wave VII brainstem convention, with the additional condition that each individual wave number is followed by an N (negative) or P (positive) suffix to separately identify each of the two peaks associated with a given wave. A positive signal at the mastoid relative to the vertex produces an upward deflection.

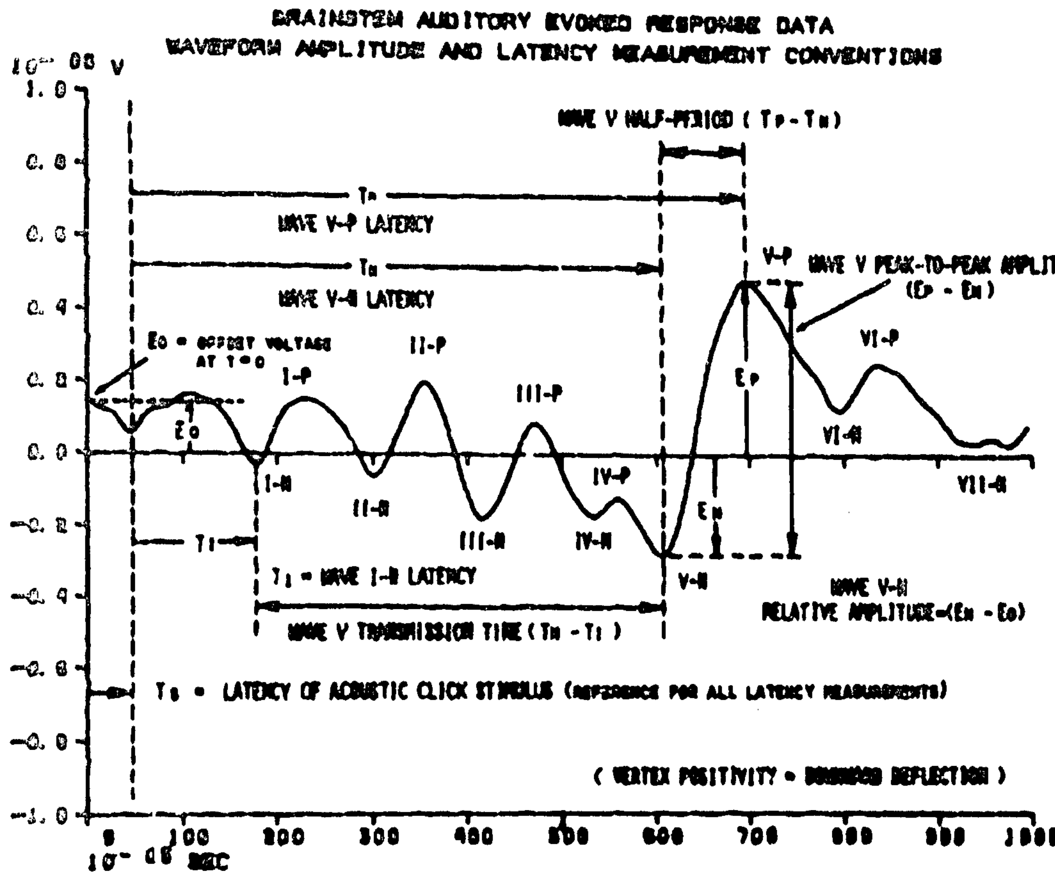


Figure 4

Selected ipsilateral brainstem recording based upon a 4000 click time-average and an 80 dB SL stimulus level showing the conventions used to measure the latency, transmission time, half-period, and peak-to-peak amplitude characteristics of the individual brainstem wave components.

0.25-millisecond time delay of the 4 kHz Bessel filter introduced between the magnetic tape recorder output and the input to the analog-to-digital converter. With Ts serving as a zero time reference, the latency of a given waveform peak is measured as the time incidence of the peak measured in the absolute units shown on the time axis less 0.468 millisecond. The transmission time of a given wave component is defined as the time interval between this peak and the initial negative directed peak of Wave I identified as I-N which is considered to correspond to VIIIth nerve activation. The half-period of a given wave is identified as the time interval between the negative and positive peaks of the given wave. The reciprocal of the total period (twice the half-period) gives a rough approximation of the fundamental frequency content of the wave. The peak-to-peak amplitude is measured as the difference between the absolute amplitude of the positive peak of the wave and the absolute amplitude of the related negative peak.

RESULTS AND DISCUSSION

To facilitate the interpretation of the brainstem data derived from the young naval aviation student population, the results are presented and discussed under seven different subheadings. The first section describes the general form and basic characteristics of the individual subject brainstem records. The second section pertains to the relative frequency of occurrence of the individual brainstem waves that were observed as a function of stimulus level. The third section describes the results of a statistical analysis of the brainstem measures recorded for the study group with the essence of the normative ipsilateral and contralateral data tabulated in Appendices A and B, respectively. In the fourth section, the results of a statistical test of the normality of the brainstem measurement variables for each of the individual brainstem waves are presented. The next two sections involve the investigation of differences between left- and right-ear brainstem responses and differences between ipsilateral and contralateral responses. The last section provides a correlation matrix analysis of relationships within and across the brainstem measurement variables for each of the individual brainstem waves.

INDIVIDUAL SUBJECT BRAINSTEM RECORDS

A consolidated display of the results of a complete testing session for a single subject who had a relatively high-amplitude brainstem auditory evoked response is shown in Figure 5. The two scaled plots at the left represent the ipsilateral (top) and contralateral (bottom) responses to left-ear stimulation. The two corresponding plots at the right describe the same responses to right-ear stimulation. As denoted by the labels shown at the center in the figure, each plot contains the brainstem records measured in response to the 40, 60, and 80 dB SL click stimuli arranged in ascending order. The horizontal amplitude axis corresponding to zero volts is in proper relationship with the 60 dB SL response (the 40 and 80 dB SL responses are plotted to the same scale as the 60 dB SL response but have been offset below and above, respectively, the zero amplitude baseline for display convenience). Each of the twelve brainstem responses shown in the figure is composed of three superimposed records: the solid line record represents the time-averaged response to 4000 clicks; and the two dotted records to either side represent the time-averaged responses to the first and second set of 2000 clicks used to construct the 4000-sample average. Although the two 2000-click time averages are plotted separately, the 4000 clicks were presented continuously to the subject without interruption.

For this subject, Waves I, II, III, V, and VI are clearly present in the ipsilateral responses to 80 dB SL stimulation of either ear. Each of these waves is marked by identifiable negative and positive peaks. In addition, the negative component of Wave VII, i.e., Wave VII-N, can be identified as occurring at approximately 9.0 milliseconds on the 10-millisecond time axis. In the case of Wave IV, neither of the two ipsilateral responses to the 80 dB SL clicks produces an identifiable response; at most, the ipsilateral response of the left ear shows a small notch on the downward negative slope of Wave V-N. However, in the simultaneously-recorded contralateral responses to the same stimuli, Wave IV, though small in amplitude, can be readily

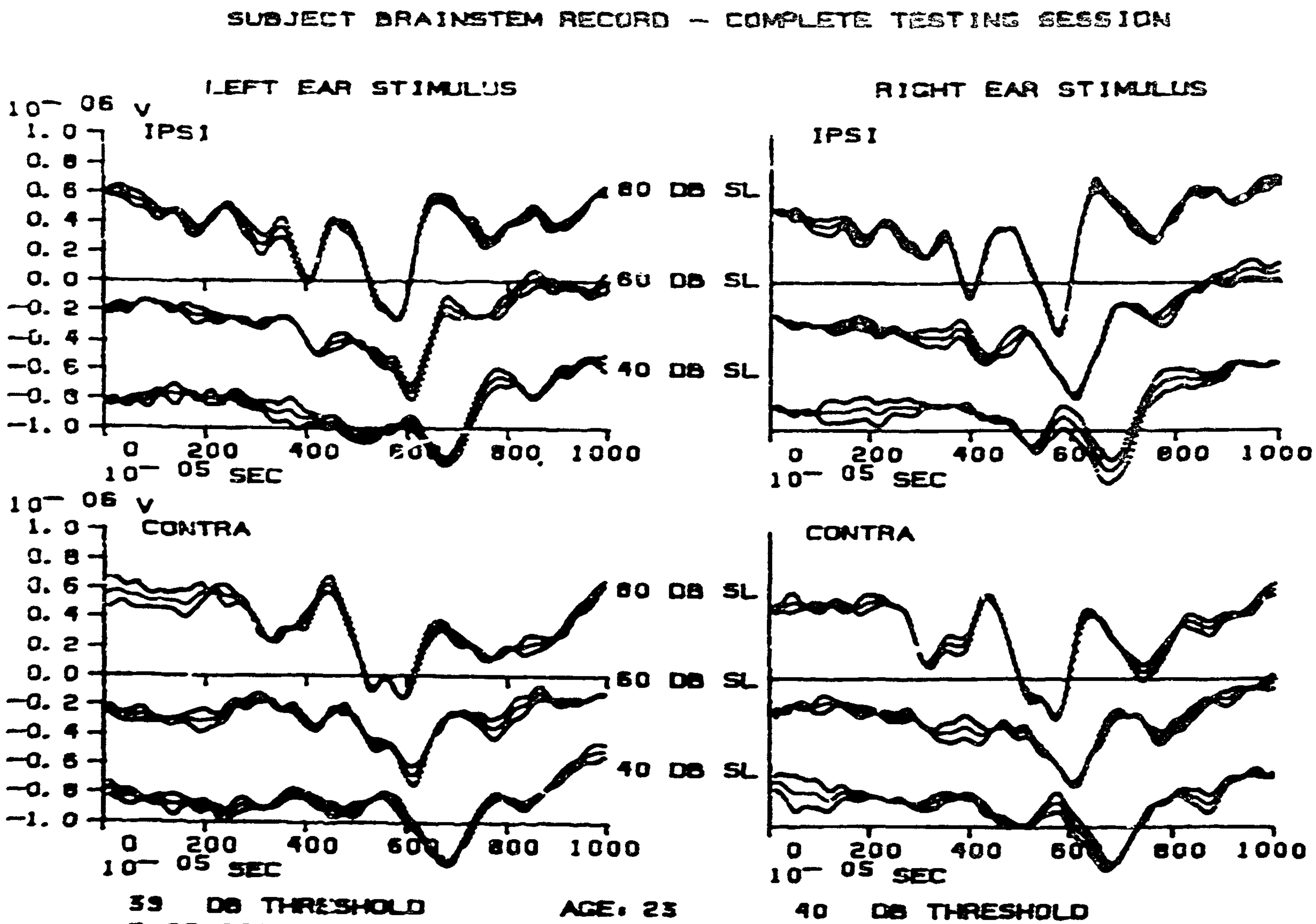


Figure 5

Digital plotter display of brainstem evoked response data collected from a single subject during a standardized testing session.

identified as occurring at approximately 5.5 milliseconds on the time axis. [The reader is reminded that the true latency of a given wave component displayed in Figure 5 is approximately 0.47 millisecond less than the latency observed on the time axis (see Procedure) as a result of the overall time delay inherent in the instrumentation system.]

The records of two additional subjects using the same display format are shown in Figure 6. The amplitude of the brainstem responses depicted in the subject record at the top is more representative of the subject group than the high-amplitude record shown in Figure 5. For the 80 dB SL ipsilateral recordings of this subject, it is more difficult to identify the wave components following Wave V-N, particularly for right-ear stimulation. The record in general, however, does illustrate the classic characteristics of the brainstem response; i.e., increasing latency and decreasing amplitude with decreasing stimuli levels. The subject record at the bottom in Figure 6 depicts a low-amplitude response and probably represents the poorest brainstem response recorded in the present series. At the 40 dB SL level, it is difficult to identify even Wave V in the ipsilateral recordings. Only the contralateral response to left-ear stimulation allows a confident identification of Wave V-N at the 40 dB level. The wide amplitude separation and sometimes uncorrelated relationship between the two 2000-sample (dotted) time-averages and the centrally located 4000-sample mean (solid) illustrate the relatively poor repeatability of the response produced by this subject.

The high-frequency noise content displayed in Figures 5 and 6 is relatively low compared to most brainstem records presented in the literature. This is accounted for, in part, by the use of the constant time-delay Bessel filter introduced between the output of the magnetic tape recorder used to store the brainstem data and the input to the computer analog-to-digital converter. Since this type of filter preserves the time-relationships that exist between the individual brainstem waves at the expense of gain constance at the higher frequencies, it would be expected that the amplitude of some of the waves displayed in Figures 5 and 6 would be slightly less than the true amplitude. With the 4-kHz cutoff frequency used in this study, the Bessel filter transfer function is such that the gain is down 3 dB at half the cutoff frequency and 13.6 dB at the cutoff frequency. It would appear that the constant time-delay feature combined with the improved high frequency signal-to-noise ratio of this type filter in the brainstem application well compensates for the small decrement in amplitude accuracy that occurs above 2 kHz.

BRAINSTEM WAVE INCIDENCE

A primary objective of the study was to utilize stimulus levels and measurement techniques which would result in a relatively high incidence of Waves I through VI in the resulting brainstem recordings. With a high incidence of readily identifiable individual brainstem waves, it becomes possible to build a data base to explore intra- and inter-wave relationships and thus extend brainstem technology beyond its most common Wave V applications. The capability of the brainstem instrumentation system of this study to accomplish this is depicted in Figure 7. These bar-graphs display the relative incidence of the negative and positive components of Waves I through

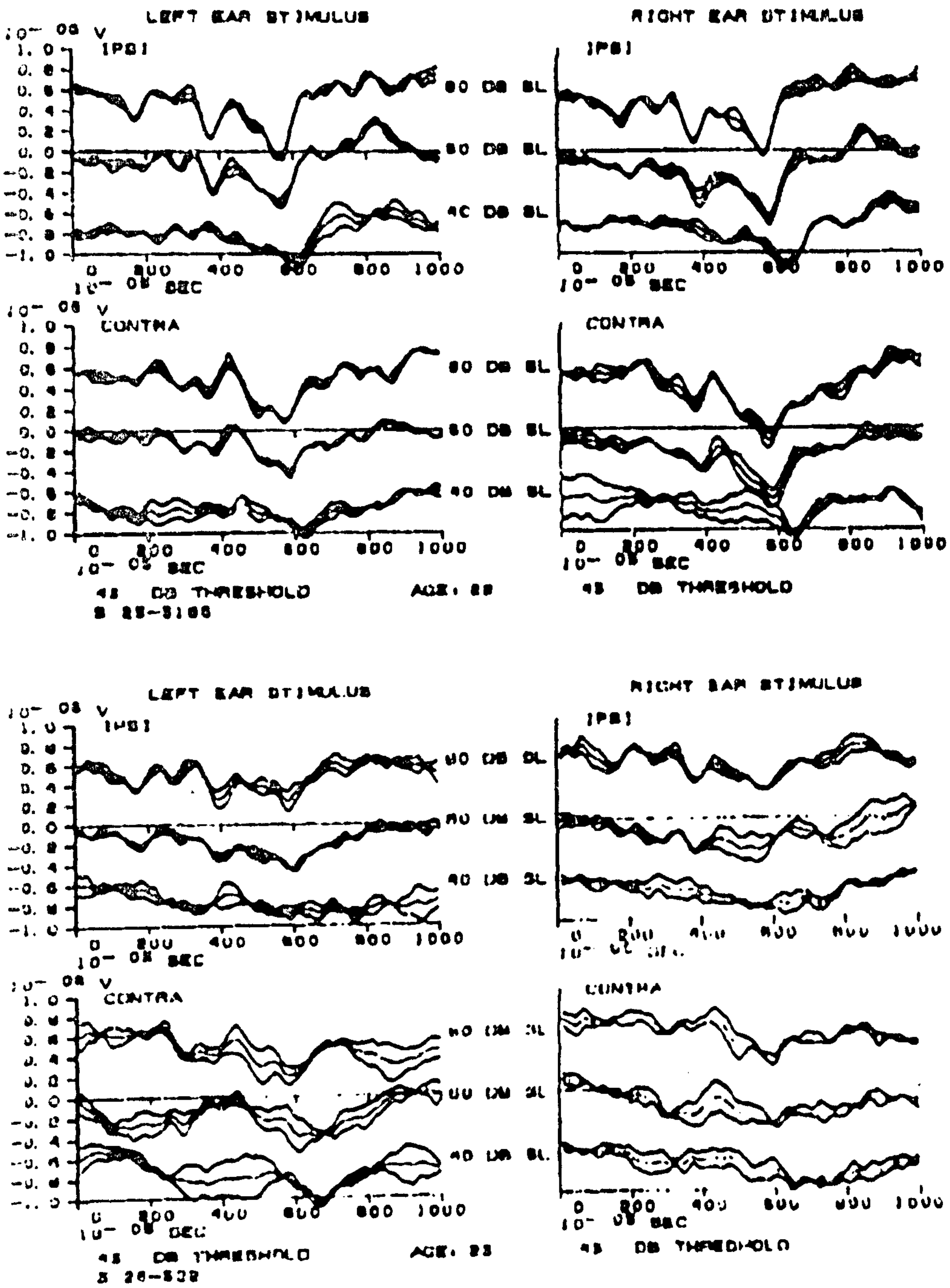


Figure 6

Comparison of the brainstem records produced by a subject with a high-amplitude response at all stimuli levels with those of a subject (26-522 bottom) having a relatively low-amplitude response with poor repeatability.

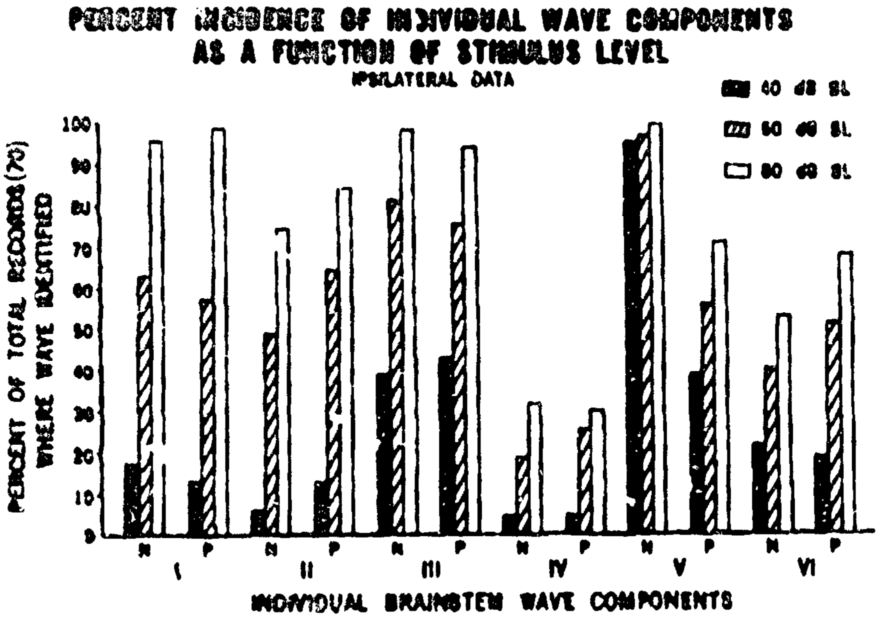
VI as a function of the 40, 60, and 80 dB SL stimuli used in the study. Each datum denotes the percentage of the total number of brainstem records analyzed (70 ears) where a given wave component was identified as being present to the extent that cursor measurements could be made of its latency and amplitude. The data used to construct these ipsilateral and contralateral plots were extracted from the rightmost column of Tables AI and BI, respectively, of the appendices.

Inspection of Figure 7 shows that, as would be expected, only the major brainstem wave, i.e., Wave V-N, had an incidence level of 90 percent or more in both the ipsilateral and contralateral recordings and for all three stimulus levels. At only the 80 dB SL level was it possible to achieve a relatively high identification level for the remaining waves. For the ipsilateral recordings made at this stimulus level, Waves I-N and I-P were identified in 96 and 99 percent, respectively, of the total number of records analyzed; Waves II-N and II-P, 74 and 84 percent, respectively; Waves III-N and III-P, 99 and 94 percent, respectively; Waves IV-N and IV-P, 31 and 30 percent, respectively; Waves V-N and V-P, 100 and 71 percent, respectively, and Waves VI-N and VI-P, 53 and 69 percent, respectively. In effect, at the 80 dB SL stimulus level, all wave components were present in the ipsilateral recordings at an incidence level of 70 percent or greater, with the exception of IV-N, IV-P, and VI-N. At the stimulus levels below 80 dB SL, the probability of identifying a given wave, with the exception of Wave V-N, fell significantly. For the contralateral recordings made at 80 dB SL, only wave components I-P, III-N, III-P, and V-N had an incidence level near or above 70 percent.

Salter and Brackman (25), using 83 dB HL (121 dB peak equivalent Lp) clicks presented at a 20-Hz rate, reported incidences of 81, 77, 93, 73, and 100 percent for Waves P1 through P5 (Waves I-N through V-N of the present study) for their 100 control ears. These data are in essential agreement with the ipsilateral data of Figure 7, with the exception of the high incidence of Wave P4 (IV-N). This difference may arise from the fact that in their study, the contralateral mastoid served as ground while in the present study, the forehead served as ground. The vertex and ipsilateral mastoid electrode sites served as the active differential inputs in both studies.

One noticeable difference between the ipsilateral and contralateral data of Figure 7 involves the incidence of the two Wave I components. At 80 dB SL, the first component, Wave I-N, had a relatively high incidence (96 percent) in the ipsilateral recordings and a low incidence (19 percent) in the contralateral recordings. The following component, I-P, has a relatively high incidence in both recording modes. The lack of a Wave I-N in the contralateral recordings is demonstrated by the 80 dB SL recordings shown in Figure 5. Both ears of this subject show a clear Wave I-N in the ipsilateral recordings and no corresponding response in the contralateral recordings. The occasional presence of a small I-N response in the contralateral recordings is demonstrated by the 80 dB SL, left-ear stimulus record at the top-left in Figure 6.

This absence of Wave I-N in the contralateral recordings (13,33,36) would be expected from the conclusion of Jewett and Williston (13) that



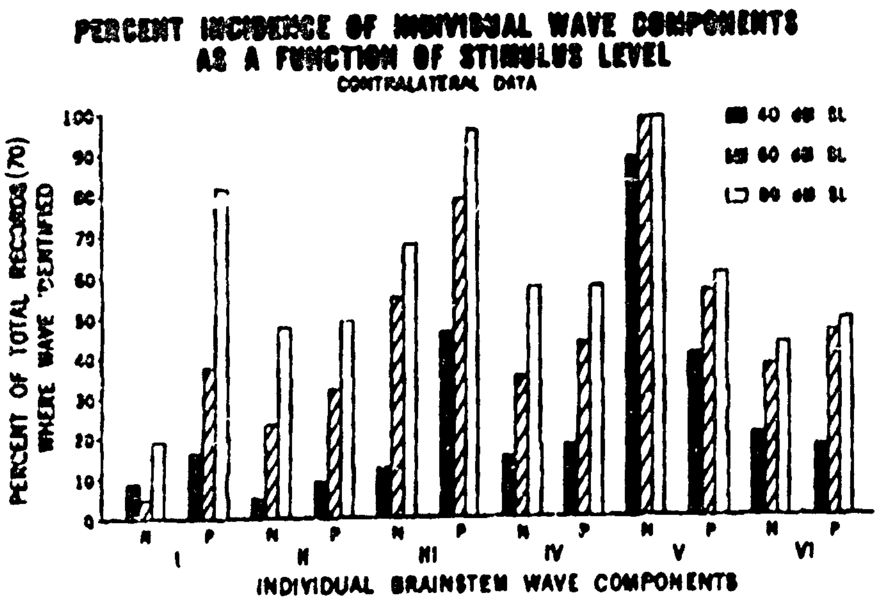


Figure 7

Bar graph plots of the percent occurrence of the individual brainstem wave components as a function of the 40, 60, and 80 dB SL stimuli levels for ipsilateral recordings (top) and contralateral recordings (bottom) for the age 20-24 population of 35 naval aviation students.

Wave I-N corresponds to the N1 potential of electrocochleography (41) which reflects VIIIth nerve activity of the stimulated ear. The relatively high incidence of Wave I-P in both the ipsilateral and the contralateral recordings lends further support to the general belief that Wave I-N is mastoid originated while the subsequent waves are more vertex oriented (32).

This vertex-orientation interpretation of all waves following I-N is complicated, however, by the Wave IV incidence data of Figure 7. Although all other waves showed the greatest incidence in the ipsilateral recordings, the converse was true for Wave IV. In the contralateral recordings, Wave IV was identified as being present in approximately 57 percent of the records; in the ipsilateral recordings, the identification rate was only 30 percent. This relationship is illustrated by the left-ear, 80 dB SL brainstem record shown in Figure 5. For this subject, a small but distinct Wave IV is visible in the contralateral recording on the downward negative slope of Wave V-N. In the corresponding ipsilateral record, the presence of Wave IV is indicated only by a slight break in the Wave V-N slope. Typically, if Wave IV could be identified in the ipsilateral recordings, then it was generally possible to readily identify a Wave IV of greater magnitude in the contralateral recordings. The converse was not true. This observation will be later discussed in relation to other differences observed between the ipsilateral and contralateral responses.

To this point no mention has been made of Wave VII. At the beginning of the study, an attempt was made to identify and measure both the negative and positive components of the wave. For many of the subjects it was readily possible to identify a relatively slow negative component occurring about 9 milliseconds or so after the click stimulus. The 80 dB SL ipsilateral recordings in Figure 5 indicate this type of response. But in other subjects, Wave VII-N was not so readily identified and was sometimes complicated by a relatively fast and small wave that occurred immediately after Wave VI-P. During a pilot statistical analysis of the small amount of Wave VII data that had been collected, it was found that the mean latency of Wave VII-N was greater than the latency of Wave VII-P which, by definition, must follow its negative counterpart. This incongruous result indicated that the criteria used by the investigators to identify Wave VII were not consistent across the subject group. If Wave VII is of post auricular muscle origin as thought probably by Picton et al. (reference 18-Figure 10), then this would account for its inconsistent presence or misidentification in the records of this study. For these reasons, statistical data pertaining to Wave VII are not included in the present analysis.

A last observation relative to the 80 dB SL ipsilateral records of this study involves the occasional occurrence of a small positive peak immediately preceding Wave I-N. This may be observed in the Figure 3 records for subjects 825-2286, 825-2178, 825-3366, and 825-1256. Mouney et al. (16) have identified such a positive wave as P_0 while Yoshie (reference 40-Figure 1) has presented a record with a corresponding peak which he relates to the summating potential (7). It is not known at this point if these small positive inflections are due to stimulus artifacts or electrophysiological activity.

BRAINSTEM MEASUREMENT STATISTICS

The results of the statistical analyses made of the brainstem data derived from the cursor measurement of the latency and amplitude of each identifiable wave peak for each individual subject are tabulated in Appendix A for the ipsilateral recordings and in Appendix B for the contralateral recordings. Each of these appendices contains separate tables describing the four basic response measurements of concern to this study; viz, latency, transmission time, half-period, and peak-to-peak amplitude. For each of these measurement parameters, for each of the three stimulus levels, and for each of the brainstem wave components, a listing is presented of the mean, median, minimum value, maximum value, range of values, standard deviation, standard error of the mean, the number of measurements (ears) comprising the sample, and the number of measurements expressed as the percentage of the total number of ears--70--available for analysis. All data used in the calculation of these group statistics were derived from cursor measurements made on the 4000-sample time-averaged brainstem recordings.

The mean and standard deviation data associated with the latency of the individual brainstem wave components have been extracted from Table AI and plotted for reader convenience in Figure 8. Corresponding ipsilateral data have been extracted from Tables AII, AIII, and AIV for the transmission time, half-period, and peak-to-peak amplitude measurements, respectively, and plotted in Figures 9, 10, and 11, respectively. In each of these figures, the three data points plotted above a given wave identification symbol correspond to the mean, plus and minus one standard deviation, of the responses produced at the 40, 60, and 80 dB SL stimulus levels (reading from left to right). These three data points are equally spaced along the horizontal axis and thus represent an abbreviated stimulus input/response output curve for each individual brainstem wave component. Those mean data points plotted without standard deviation limits denote response samples with an n less than five for which, as an arbitrary decision, statistical calculations were not performed.

The pattern of the ipsilateral latency data plotted in Figure 8 is as would be expected in that all twelve wave components show a decrease in latency with an increase in stimulus level. For the majority of the waves, the standard deviation of the latency measurements decreases as the stimulus level is raised, reflecting the improved signal-to-noise ratio conditions. The standard deviations of both components of Wave VI were relatively large and more or less independent of stimulus level. This observation may be related to the occasional difficulties encountered in identifying the exact peaks of this particular wave.

As has been emphasized previously, across the board comparisons of latency and amplitude data produced by different laboratories are complicated by the many differences that exist between measurement equipment and techniques. The best comparative reference for the data of the present study is probably afforded by the bilateral work of Thornton (34-37) who also recorded similar simultaneous ipsilateral and contralateral responses and measured the response characteristics of both the negative and positive components of each individual brainstem wave. In general, the latency data of Table AI

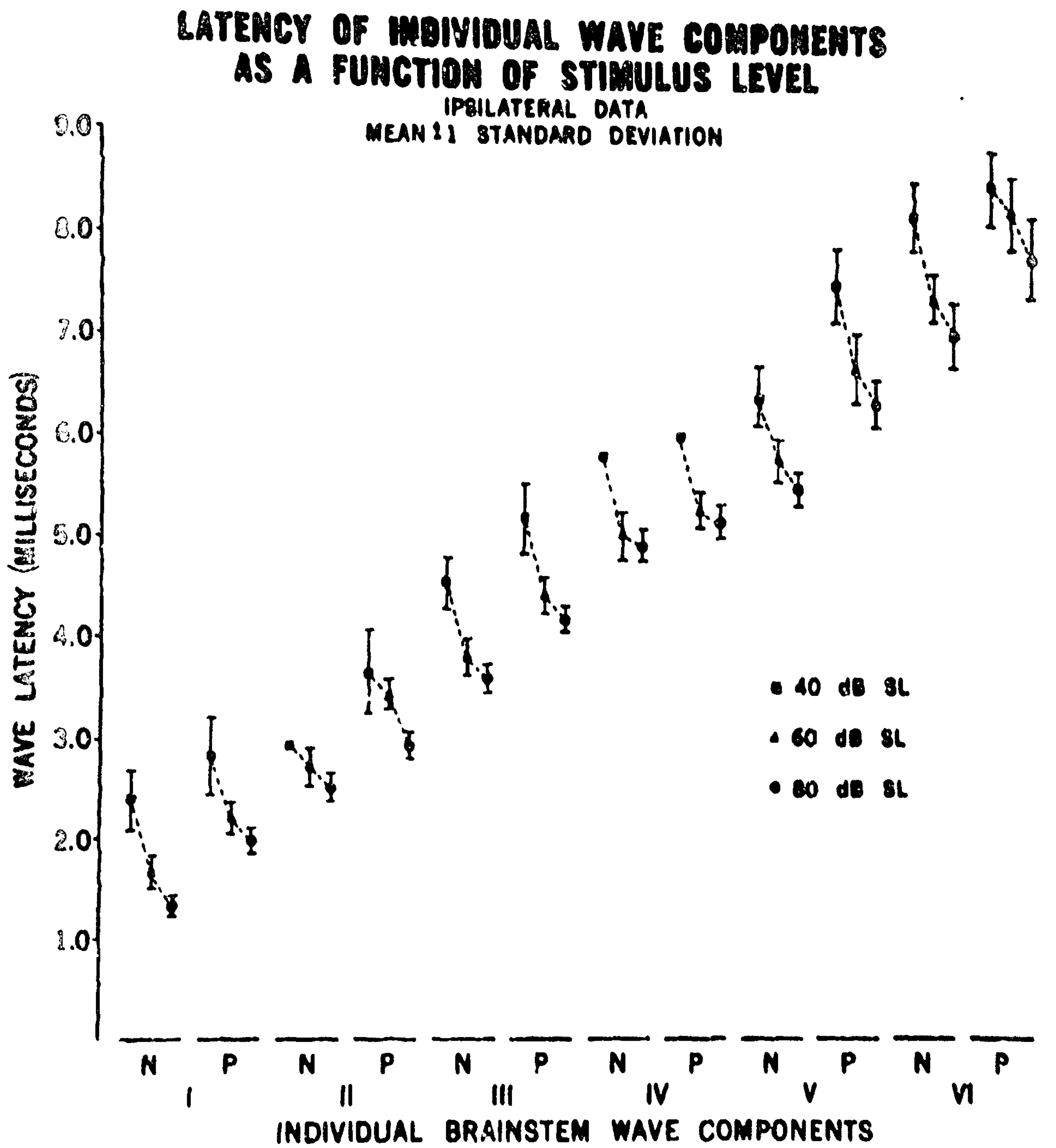


Figure 8

Plot of the mean (plus and minus one standard deviation) ipsilateral latency of the individual brainstem wave components as a function of stimulus level based on 70 ears (35 subjects).

and Figure 8 follow those reported in the literature. For example, the 60 dB SL ipsilateral data for the negative wave components of this study closely match (within 0.1 millisecond for all waves but Wave I) the 60 dB data reported by Picton et al. (18); are slightly shorter than the 60 dB SL-30 Hz click rate latencies reported by Rowe (23) for his younger population; are slightly longer than the 90 dB Lp-10 Hz click rate latencies reported by Zollner, Karnahl, and Stange (43); are considerably longer than the 60 dB SL-10 Hz click rate latencies reported by Berry (2); and are fairly well related (both negative and positive wave components) to the 60 dB SL data reported by Thornton (35). For the 80 dB SL data of this study, the latencies of Waves II-N through VI-N are, in general, slightly longer than those reported by Lev and Sohmer (14) and by Lieberman, Sohmer, and Szabo (15) using 75 dB HL click stimuli presented at a 10-Hz rate. The latencies of Waves I-N and V-N at the 40, 60, and 80 dB SL stimulus levels of the present study all fall within the plus and minus one-standard deviation boundary limits of the composite laboratory data plotted by Picton et al. (19).

One observation of interest in Figure 8 (derived from Table AI) involves the potential existence of a latency nonlinearity with the three stimulus levels used in the study. With the exception of both components of Wave II, and the positive component of Wave VI, the decrease in latency that occurs between 40 and 60 dB SL is considerably greater than the decrease that occurs between 60 and 80 dB SL. For example, the latency of Wave I-N at 40 and 60 dB SL is approximately 2.36 and 1.65 milliseconds, respectively, representing a decrease of approximately 0.7 millisecond. At 80 dB SL, the Wave I-N latency is 1.33 milliseconds, thus representing a decrease of only 0.32 millisecond from the latency at 60 dB SL. This nonlinearity is also reflected by the Wave V-N latency data; i.e., 6.38, 5.75, and 5.47 milliseconds at the 40, 60, and 80 dB SL stimulus levels, respectively. As discussed earlier, these three stimulus levels were referenced to a 40 dB SPL mean sensory threshold for the group. In this respect, it is possible that the observed latency nonlinearity may be due to the relatively high sound pressure level (120 dB peak) associated with the 80 dB SL stimulus. The Wave I-N nonlinearity corresponds roughly to the break in the N1 latency data plotted by Yoshie (reference 39-Figure 2) which occurs around 60 dB SL which in turn is fairly close to the transition level which separates his "H" and "L" amplitude input-output curves. The data of Cullen et al. (5) also indicate a nonlinearity in the N1 (Wave I-N) latency response over the 60-110 dB Lp stimulus range. This nonlinearity, however, was of exponential rather than of discontinuous or break form. The latency data plotted by Zollner, Karnahl, and Stange (43) also indicate the potential for nonlinearity with stimuli in the 80 to 100 dB Lp range. In this case, the trend is noticeable for not only Wave I, but also their Waves III, IV, and V.

Corresponding mean and standard deviation data, extracted from Table AII, are plotted for the ipsilateral transmission times of the individual brainstem wave components in Figure 9. As detailed earlier, the transmission time of a given wave component was defined as the time interval between the initial Wave I-N peak representing VIIIth nerve activity and the peak of the given wave component. Since the measurement of this parameter depends on the presence of an identifiable Wave I-N, and since the incidence of this

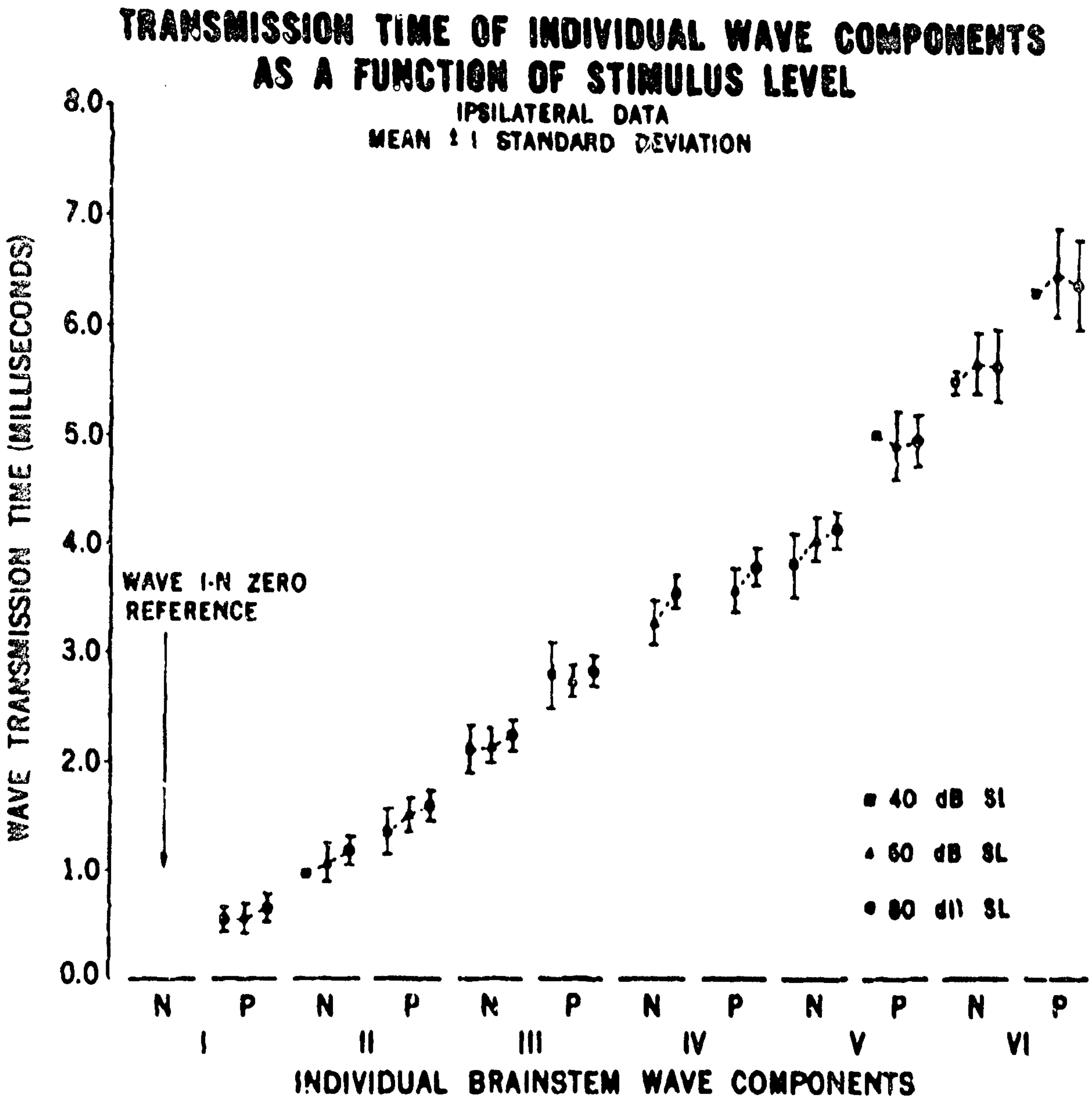


Figure 9

Plot of the mean (plus and minus one standard deviation) ipsilateral transmission time of the individual brainstem wave components as a function of stimulus level (data extracted from Appendix A, Table A 11).

wave decreases at the lower stimulus levels, the number of individual transmission time data available for statistical analysis is considerably lower than the number available for analysis of the latency data. As indicated in Figure 9, there was a general trend for the mean transmission times of the individual wave components to increase as stimulus level was raised. Exceptions to this trend included Waves III-P, V-P, and both components of VI. Another general trend involved a gradual increase in the standard deviation of the measure with wave number. The trend for the standard deviation of the Figure 8 latency data to decrease with an increase in stimulus level was not so pronounced for the transmission time data.

Again, the transmission time data of this study follow, in general, those reported in the literature. Good comparison is afforded by the interpeak conduction time data of Rowe (23) who collected considerable brainstem information on two population groups widely separated in age. He also made direct comparisons of his measurements with those collected in other laboratories. For the younger population, Rowe reported transmission times of 1.09, 2.08, and 4.05 milliseconds for Waves II, III, and V, respectively, using clicks 60 dB above click threshold that occurred at a 30-Hz repetition rate. In the present study, the ipsilateral transmission times produced by 60 dB SL clicks occurring at a 21-Hz rate were 1.17, 2.24, and 4.14 milliseconds for the same three waves. Allowing for the differences in recording methods and click repetition rate that exist between the two studies, it appears that the two sets of transmission time data are reasonably well matched. Since the variations in transmission time that occurred as a function of stimulus level were relatively small, the contention of Rowe that this measure is independent of stimulus level may be true for all practical purposes. Visual inspection of the latency data plotted by Lev and Sohmer (reference 14-Figure 2a), Pratt and Sohmer (reference 21-Figure 3), and Saltore and Brackmann (reference 25-Figure 1) shows little change in transmission time as a function of stimulus level. However, visual inspection of the latency data plotted by Thornton (reference 37-Figure 9) also indicates a small increase in transmission time with increasing stimulus level for at least Wave V-N (his Wave N4). Coats (4) also reported a small increase in the transmission time of Wave V and noted that the latency data of Starr and Achor (30) are compatible with this observation.

The ipsilateral half-period data, extracted from Table AIII and plotted in Figure 10, represent the time interval between the first negative peak of a given wave and the immediately following positive component of the same wave. As with the transmission time data, the number of half-period measurements available for analysis is smaller than the number available for analysis of the latency data since both the negative and the positive components of a given wave must be present to define its half-period. This half-period parameter, not generally reported in the literature, is presented to give some insight into the fundamental frequency of each individual brainstem wave. Treating the half-period of a given brainstem wave as half the actual period of a continuous sinusoidal oscillation, the fundamental frequency of the wave can be calculated as the reciprocal of the period. In this context, it can be seen from Figure 10 that Wave IV has the shortest half-period and thus the highest fundamental frequency. In effect, the 0.24-millisecond half-period observed for the ipsilaterally recorded Wave IV at 80 dB SL

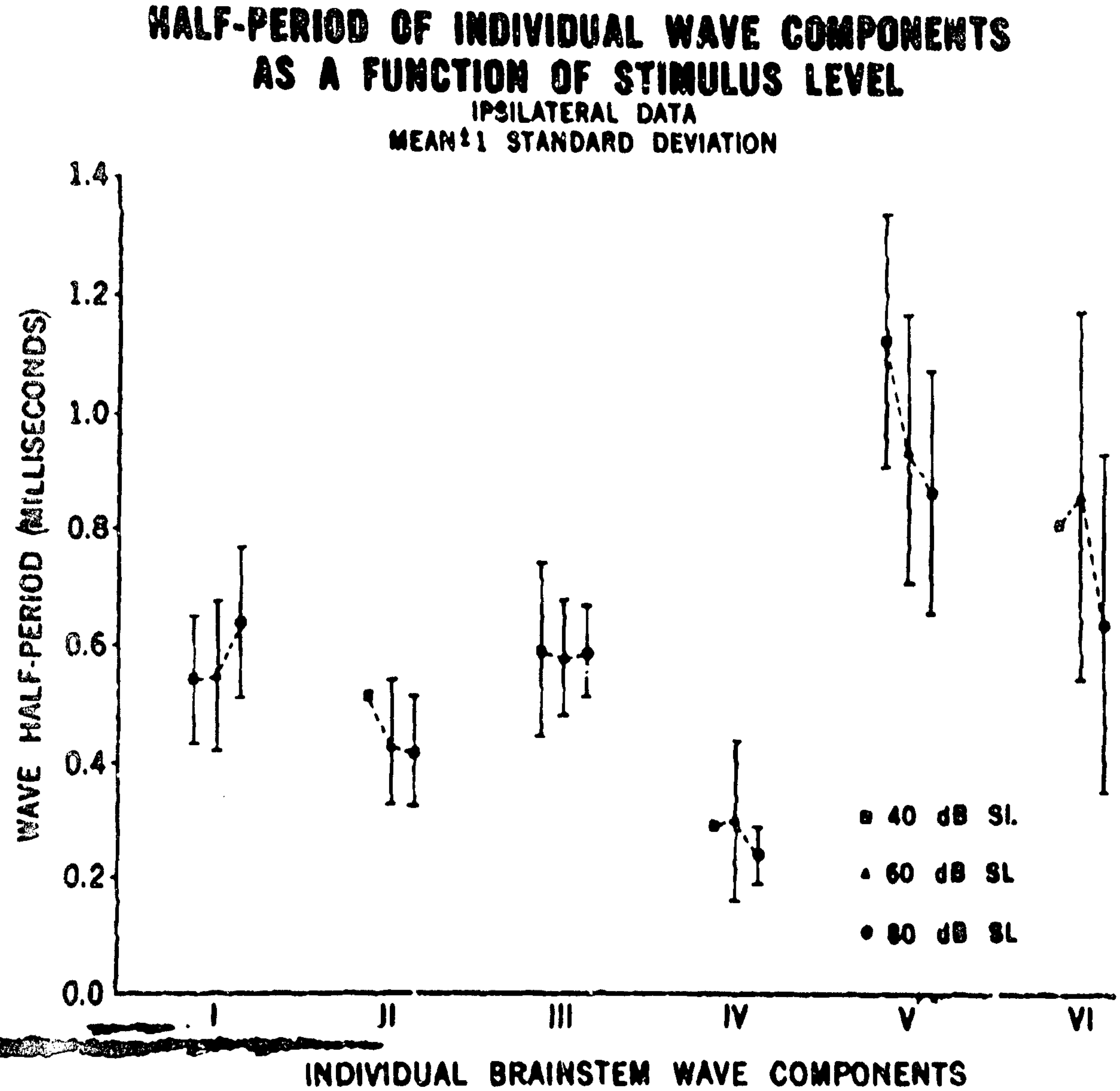


Figure 10

Plot of the mean (plus and minus one standard deviation) ipsilateral half-period of the individual brainstem wave components as a function of stimulus level (data extracted from Appendix A, Table A III).

stimulus level can be visualized as describing a wave with a fundamental frequency of approximately 2000 Hz. Equivalently, Figure 10 indicates that Wave V had the longest half-period and thus represents the lowest frequency brainstem wave; e.g., the 0.87-millisecond half-period observed at 80 dB SL signifies a fundamental frequency of approximately 575 Hz. Because of the high-frequency rolloff characteristics of the Bessel filter used in this study, it would be expected that gain attenuation would be greatest for Wave IV. Again, it is emphasized that the half-period data provide only a very rough approximation of the fundamental frequency of a given wave.

The half-period data, as reflected by the standard deviation bars in Figure 10, exhibited considerable more variation than either the latency or transmission time measurements. There is no across-the-board trend for the half-period to either increase or decrease as a function of stimulus level. Wave I showed a jump increase at 80 dB SL, Wave III displayed minimal variation, and Wave V reflected a decrease in half-period with increasing stimulus levels. It should be noted that if a trend was present for the half-period of the early waves to increase or decrease as a function of the stimulus level, then the transmission times of the later waves would increase or decrease correspondingly. In this respect, the jump in the half-period of Wave I at 80 dB SL may account in part for the increase in transmission time that accompanied an increase in stimulus level for some of the subsequent waves. A related point involves the definition of the transmission time measurement. If one wished to represent transmission time as the latency difference between the very onset of peripheral activation and a distinguishable wave peak occurring further along the brainstem route, then the onset, rather than first peak, of Wave I-N would serve as the best measurement reference. Thus if the half-period of Wave I increased as a function of stimulus level, and if the actual onset of Wave I occurred approximately a quarter-period before its first negative peak (Wave I-N), then this correction would have the tendency to make the transmission time of following waves less dependent upon stimulus level.

The measured peak-to-peak amplitudes of the individual brainstem waves have been extracted from Table AIV and plotted in Figure 11. These data also exhibit considerable variability across stimulus levels. As has been reported by others (15,21,33), the standard deviations of the amplitude data are much greater on a proportional basis than those of the latency data. On an individual subject basis, a rise in stimulus level is generally accompanied by a rise in brainstem wave amplitude. On a group basis, however, this relationship is not readily established for all of the waves analyzed. For example, Waves I, III, and V show an increase in amplitude when comparing the responses at 40 and 80 dB SL while Wave VI shows the converse. The Wave IV data of Figure 11 show the extremely low level (7 to 71 nanovolts range) of this relatively low incidence brainstem wave.

In general, the statistical properties of contralateral brainstem measurement data, summarized in Tables BI through BIV, follow those of the ipsilateral data. There are, however, differences between the mean latencies of certain of the individual wave components. These differences will be discussed in the section which addresses the two recording modes. With Thornton's (35,36) bilaterally recorded latency data (based on 6 subjects),

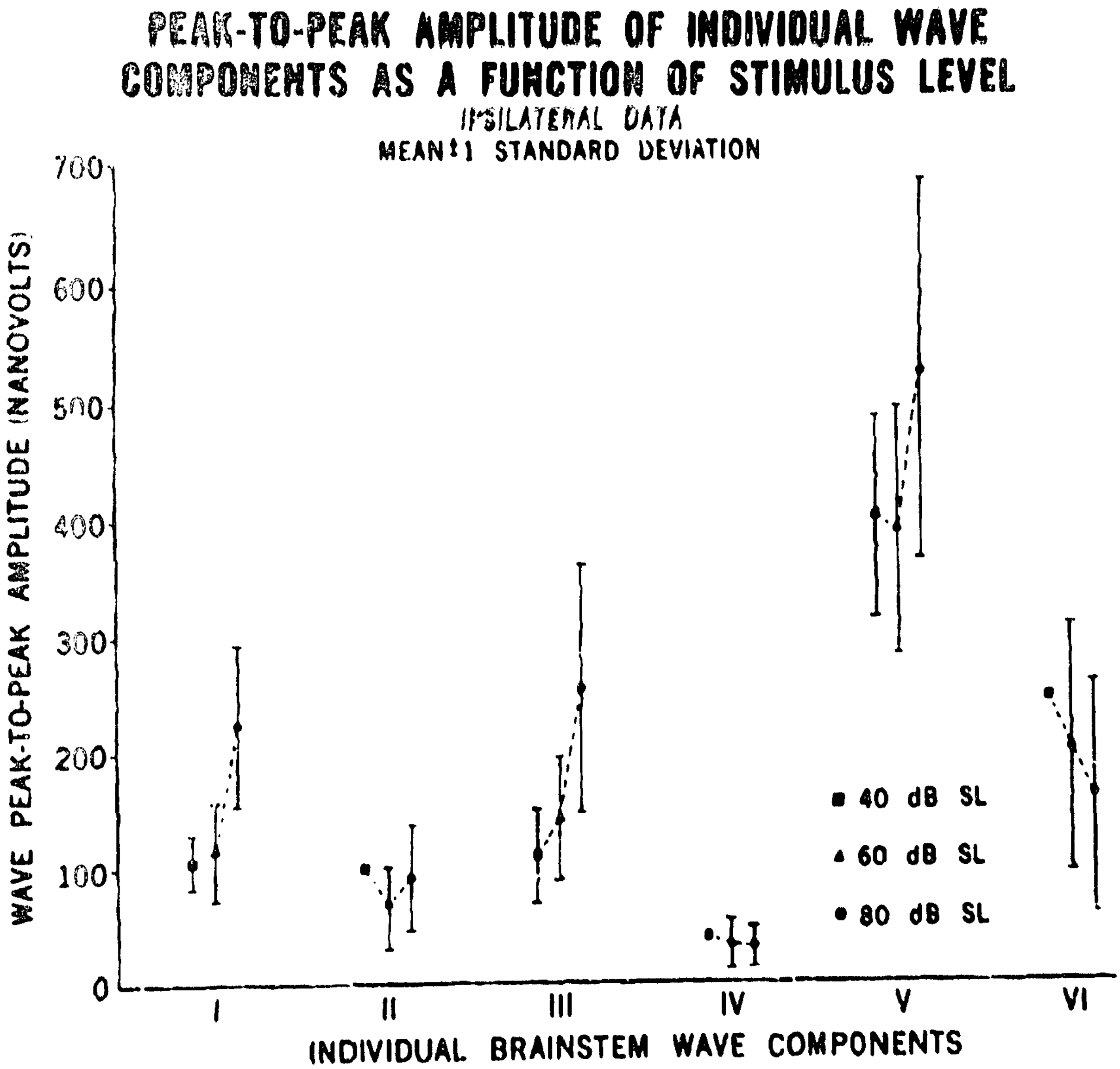


Figure 11

Plot of the mean (plus and minus one standard deviation) ipsilateral peak-to-peak amplitude of the individual brainstem wave components as a function of stimulus level (data extracted from Appendix A, Table A III).

the related standard deviations of the contralateral responses were greater than those of the ipsilateral responses. The most noticeable differences involved his Waves N3 and P5 (our III-N and VI-P). The data of the present study indicate that the standard deviations of the latency measures were approximately the same for both recording modes for all components except VI-N and VI-P. Thornton also found the ipsilateral amplitude data to be more ordered as a function of stimulus level than the contralateral amplitude data. This was not found to be the case in the present study in that the amplitude of the contralateral response produced by a given stimulus level followed, in general, that of the related ipsilateral response for all waves except VI. He also found that the ipsilateral amplitude was greater than the contralateral amplitude for all waves except II. The same trend was observed in the present study with the exception that only Wave IV had a greater contralateral amplitude. Thornton also indicated that the standard deviations of the contralateral amplitude measures were less than those of the ipsilateral measures with the differences being most noticeable in Waves III and VI. In the present study, the standard deviations of the contralateral amplitude data were less than those of the ipsilateral data for Waves I through III, and greater than the ipsilateral responses for Waves IV and VI.

STATISTICAL DISTRIBUTION OF THE BRAINSTEM MEASUREMENT DATA

In the discussion of the brainstem data presented in Appendices A and B no mention was made of the statistical distribution of the individual observations used to construct the group statistics for the latency, transmission time, half-period, and peak-to-peak amplitude measurements of the study. To test the normality of the distributions associated with all four measurement variables and all twelve brainstem wave components, a Kolmogorov-Smirnov one-sample test of goodness-of-fit (26) of the cumulative frequency distribution of the observed data to an equivalent Gaussian distribution was applied to the study data. Such an analysis, performed by Thornton (36) on the latency and amplitude measurements derived from six subjects, is of value when weighing the decision to use parametric or nonparametric statistics to analyze selected response differences and correlations.

To implement the Kolmogorov-Smirnov test, a normalized cumulative frequency distribution for a Gaussian population was constructed with the same mean and standard deviation as those of the observed data. The maximum deviation on a point-to-point basis between this theoretical distribution and the normalized cumulative frequency distribution of the observed data was calculated. The results of the test for each of the brainstem waves are listed in Table I for the ipsilateral responses to the 80 dB SL stimulus condition for all four measurement variables (70 ears). The absolute value of the maximum deviation found between the two distributions, and the number of measurements used in the calculation of the observed data distribution are shown below each of the identified wave components. Only the latency and transmission time measures involve both the negative and positive wave components since the remaining two brainstem measures are based on differences between the two components associated with a given wave. For the latency measurements, the null hypothesis that there was no difference between the observed and theoretical Gaussian distributions could not be disproved at a significance level of .05 or greater for any wave component

Table I

Kolmogorov-Smirnov one-sample test of goodness of fit of the cumulative frequency distributions of the observed latency, transmission time, half-period, and peak-to-peak amplitude measurements of the individual brainstem waves relative to equivalent Gaussian distributions. Calculations based on ipsilateral responses to 80 dB SL stimuli involving 70 ears.

STATISTICAL VARIABLE		INDIVIDUAL BRAINSTEM WAVES											
		I-N	I-P	II-N	II-P	III-N	III-P	IV-N	IV-P	V-N	V-P	VI-N	VI-P
Latency	(D)	.10	.10	.09	.12	.09	.11	.11	.13	.08	.07	.07	.22*
	(n)	67	69	52	59	69	66	22	21	70	50	37	48
Transmission Time	(D)	.10	.16	.10	.12	.13	.12	.13	.10	.07	.07	.08	.27**
	(n)	67	66	51	50	66	63	22	21	67	48	36	45
Half-Period	(D)	.16		.10		.05		.08		.12		.10	
	(n)	66		51		66		21		50		28	
P-P Amplitude	(D)	.05		.14		.09		.24		.12		.17	
	(n)	66		51		66		21		50		28	

(D) = Absolute value of maximum deviation of the normalized cumulative frequency distribution of the observed data from the normalized cumulative frequency distribution of Gaussian data.

(n) = Number of individual measurements.

* Significant beyond the .05 level.

** Significant beyond the .01 level.

other than Wave VI-P. The same applied to the transmission time data, with the exception that the deviation observed for Wave VI-P was significant at the .01 level. For the half-period and peak-to-peak amplitude data, there was no evidence that the distributions of either of these measures differed significantly from equivalent Gaussian distributions for any of the six brainstem waves. In effect, for only wave component VI-P, and for only the latency and transmission time measurements associated with this component, is there any statistical evidence to imply a non-Gaussian distribution of the measurement data. Thornton (36) also reported finding no evidence for significant departure from normality for both his latency and amplitude data.

Because of the lower n associated with these measurements at stimulus levels below 80 dB SL, the same Kolmogorov-Smirnov one-sample test of goodness-of-fit was applied to only the predominant waves; i.e., Waves III and V, at the 40 and 60 dB SL stimulus levels. Again, no evidence could be found for any of the four measurements made on the negative and positive components of these two waves that would indicate a non-Gaussian distribution at these lower stimulus levels.

The same goodness-of-fit test was also applied to the 80 dB SL contralateral measurement data listed in Tables BI through BIV. In this case,

no evidence was found to indicate that the distributions of any of the four measurements associated with any of the twelve wave components differed significantly from equivalent Gaussian distributions. [It should be noted, however, that because of the relatively low incidence of Wave I-N in the contralateral recordings (identified in only 13 of the 70 ears at this stimulus level), the Kolmogorov-Smirnov test for the transmission time measurements was based on a relatively low *n*.]

LEFT/RIGHT EAR DIFFERENCES

To determine if any differences existed in the ipsilateral responses of the left and right ears of this young population, a matched-pair Student *t*-test was applied to each of the four measurement variables for each of the individual wave components at the 80 dB SL stimulus level. The results of this test, based on a comparison of the differences between the left- and right-ear responses of each of the 35 subjects, are presented in Table II. The table lists the left-ear mean, the right-ear mean, the linear correlation coefficient between the two measurements, the matched-pair Student *t*-statistic, and the number of data pairs involved in the calculation for each of the individual brainstem wave components. A probability level of .01 or less was selected to establish the minimum statistical significance required to define a difference. This relatively stringent criterion was selected in the interest of identifying real differences at the expense of overlooking true, but borderline differences between the ears.

Examination of the *t*-statistic, identified as "*t*-means," in Table II for each brainstem wave component and for each measurement variable indicates that there were no significant differences between the means for the left- and right-ear responses for this subject group. Selters and Brackman (25) have investigated the potential of using Wave V latency differences between the two ears to detect acoustic tumors. The majority of their normal subjects had Wave V interaural latency differences between 0 and 0.1 millisecond in response to 120 dB peak equivalent Lp click stimuli (83 dB HL) presented at a 20-Hz repetition rate. Interaural latency differences greater than 0.2 millisecond were considered to be suspect with the size of the tumor related to the magnitude of the difference. As indicated in Table II, the differences in our study between the mean latencies for the two ears were extremely small for all twelve wave components. For Wave V-N, the latency difference between the means was less than 0.02 milliseconds for this select normal population; the maximum left/right difference observed within the population was 0.24 millisecond. For the negative and positive components of Waves I through VI, the standard deviations of the left/right latency differences were 0.11, 0.11; 0.08, 0.15; 0.10, 0.12; 0.04, 0.12; 0.12, 0.26; and 0.28, 0.58 millisecond respectively. For this population, a Wave V-N interaural latency difference of 0.25 millisecond (mean difference plus and minus 2 standard deviations) would incorporate the responses of all 35 subjects. The standard deviation of the Wave V-N interaural difference for the 80 dB SL contralateral recordings was approximately the same (0.11 millisecond) as that of the ipsilateral differences.

Table II

Matched-pair Student t-test statistics for left ear/right ear differences in the means of the ipsilateral latency, transmission time, half-period, and peak-to-peak amplitude measurements for the individual brainstem evoked response waves. The data are based upon 4000-sample time-averaged responses of 35 pairs of ears to 80 dB SL acoustic click stimuli presented at a 21 Hz repetition rate.

LEFT/RIGHT COMPARISON STUDENT t-Test STATISTICS	INDIVIDUAL BRAINSTEM WAVES - IPSILATERAL DATA											
	I-N	I-P	II-N	II-P	III-N	III-P	IV-N	IV-P	V-N	V-P	VI-N	VI-P
LATENCY - millisec												
Left Ear Mean	1.32	1.98	2.47	2.95	3.58	4.17	4.93	5.17	5.46	6.32	7.02	7.81
Right Ear Mean	1.35	1.97	2.51	2.92	3.57	4.16	4.95	5.19	5.48	6.33	6.98	7.71
Correlation	.34	.67***	.81***	.47	.74***	.65***	.97**	.91	.76***	.46	.68	.03
t-Means	-1.81	.91	-2.67	1.14	.69	.16	-.78	-.45	-1.26	-.15	.43	.74
n-Pairs	32	34	22	26	34	32	5	5	35	21	11	18
TRANSMISSION TIME - millisec												
Left Ear Mean	—	.66	1.15	1.63	2.26	2.85	3.62	3.86	4.14	4.99	5.63	6.51
Right Ear Mean	—	.60	1.17	1.57	2.21	2.80	3.59	3.84	4.13	4.97	5.62	6.29
Correlation	—	.26	.48	.12	.46**	.58***	.63	.62	.69***	.52	.77**	.22
t-Means	—	2.02	-1.00	1.56	2.03	1.78	.53	.32	.24	.41	.10	1.60
n-Pairs		32	22	26	31	29	5	5	32	19	10	15
HALF-PERIOD - millisec												
Left Ear Mean	.66		.46		.59		.24		.87		.70	
Right Ear Mean	.67		.41		.60		.25		.86		.70	
Correlation	.26		.37		-.28		-.65		.38		.88	
t-Means	2.02		2.17		-.32		-.14		.20		.003	
n-Pairs	32		21		32		5		21		6	
PEAK-TO-PEAK AMPLITUDE - nanovolts												
Left Ear Mean	228		104		244		25		522		178	
Right Ear Mean	221		91		270		38		534		179	
Correlation	.50**		.22		.80***		-.58		.91***		.91	
t-Means	.59		.95		-1.99		-.77		-.58		-.05	
n-Pairs	32		21		32		5		21		6	

** Significant beyond the .01 level.
*** Significant beyond the .001 level.

IPSILATERAL/CONTRALATERAL DIFFERENCES

The matched-pair Student t-test was also utilized to compare the individual brainstem wave measurements of the simultaneously recorded ipsilateral and contralateral responses. The results of this comparison are presented in Table III, which utilizes a format identical to that of Table II. Each matched-pair data set involves the comparison of the ipsilateral mean response to the contralateral mean response of the same ear for a given subject. The left and right ear responses of the 35 subjects to 80 dB SL stimulation were treated as separate responses, resulting in a total of 70 ears. In Table III, negative values for the t statistic indicate that the magnitude of the ipsilateral response mean is less than the magnitude of the related contralateral response mean. Referring first to the latency data of Table III, it may be seen that statistically significant differences exist between the ipsilateral and contralateral latencies. In the ipsilateral recordings, Wave Components I-P, II-N, II-P, and V-N significantly precede the corresponding components in the contralateral recordings. Conversely, both components of the ipsilateral Wave III lag the corresponding components of the contralateral recordings. These differences are significant to the .001 level or better. The latency correlation coefficients shown in Table III indicate that there was no significant relationship between the ipsilateral and contralateral responses for Wave component I-N and Wave VI. All other wave components were correlated to the .001 or better significance level, with the exception of Wave I-P which had a significance level of .01 or better.

The latency differences between the ipsilateral and contralateral responses just mentioned are obviously of small magnitude. For example, the mean latency data for Wave V-N indicate that the ipsilateral response for this subject group preceded the corresponding contralateral response by only 0.12 millisecond. Although of small magnitude, the difference was found to be present in over 82 percent of the subject records. That is, of the 70 ears examined, the ipsilaterally recorded Wave V-N preceded its contralateral counterpart in 58 cases, equaled it in 7 cases, and lagged behind it in only 5 cases. Examination of the basic latency data for Wave III-P on an individual subject basis showed an even more pronounced pattern. Of the 64 ears which produced an identifiable Wave III-P, the contralateral response preceded the ipsilateral response in 59 cases, equaled the ipsilateral response in 3 cases, and preceded the response in only 2 cases.

Figure 12 is presented to further illustrate the real nature of these ipsilateral and contralateral latency differences. At the left in the figure, brainstem responses produced by 80 dB SL click stimulation of the left ear are plotted for five different subjects. For each subject the contralateral response is superimposed in a dotted pattern on the solid-line ipsilateral response. The records at the right pertain to the corresponding responses of the same subjects produced under right-ear stimulus conditions. For the subject record shown at the top, identified as Subject S-21, both components of the contralateral Wave III clearly precede the ipsilateral Wave III for both left- and right-ear stimulation. The contralateral Wave V-N only slightly lags its ipsilateral counterpart. The right-

Table III

Matched-pair Student t-test statistics for ipsilateral/contralateral differences in the means of the latency, transmission time, half-period, and peak-to-peak amplitude measurements for the individual brainstem evoked response waves. The data are based upon 4000-sample time-averaged responses of 70 ears to 80 dB SL acoustic click stimuli presented at a 21 Hz repetition rate.

IPSI/CONTRA COMPARISON STUDENT t-Test STATISTICS	INDIVIDUAL BRAINSTEM WAVES											
	I-N	I-P	II-N	II-P	III-N	III-P	IV-N	IV-P	V-N	V-P	VI-N	VI-P
LATENCY - millisec												
Ipsi Ear Mean	1.36	1.98	2.49	2.93	3.57	4.17	4.94	5.17	5.47	6.29	7.03	7.65
Contra Ear Mean	1.41	2.06	2.66	3.03	3.46	3.99	4.89	5.19	5.59	6.31	6.98	7.72
Correlation	.38	.37**	.72***	.73***	.85***	.72***	.77***	.91***	.80***	.83***	.47	.005
t-Means	-1.61	-4.07***	-9.04***	-5.65***	9.60***	13.27***	2.18	-1.29	-8.59***	-.83	.63	-.53
n-Pairs	12	56	31	30	46	64	17	15	69	33	20	26
TRANSMISSION TIME - millisec												
Ipsi Ear Mean	—	.61	1.09	1.56	2.22	2.82	NC	NC	4.08	4.86	5.42	NC
Contra Ear Mean	—	.57	1.25	1.64	2.04	2.55	NC	NC	4.11	4.82	5.25	NC
Correlation	--	-.37	.59	.04	.37	.24	NC	NC	.87***	.70	.04	NC
t-Means	—	1.18	-5.57***	-1.62	3.99**	5.57***	NC	NC	-1.18	.73	.84	NC
n-Pairs	—	12	9	10	10	12	2	1	12	8	6	4

	I	II	III	IV	V	VI
HALF-PERIOD - millisec						
Ipsi Ear Mean	.61	.45	.59	.23	.84	.65
Contra Ear Mean	.57	.37	.54	.30	.75	.74
Correlation	-.37	.44	.07	.45	.69***	-.11
t-Means	1.18	4.80***	2.86**	-4.78***	2.65	-.71
n-Pairs	12	22	44	15	33	10
PEAK-TO-PEAK AMPLITUDE - nanovolts						
Ipsi Ear Mean	258	106	252	25	555	231
Contra Ear Mean	127	60	189	64	355	219
Correlation	.29	.43	.90***	.28	.37	.59
t-Means	6.19***	4.15***	8.61***	-4.24***	7.05***	.27
n-Pairs	12	22	44	15	33	10

** Significant beyond the .01 level.
*** Significant beyond the .001 level.

NC = Not Calculated, n < 5

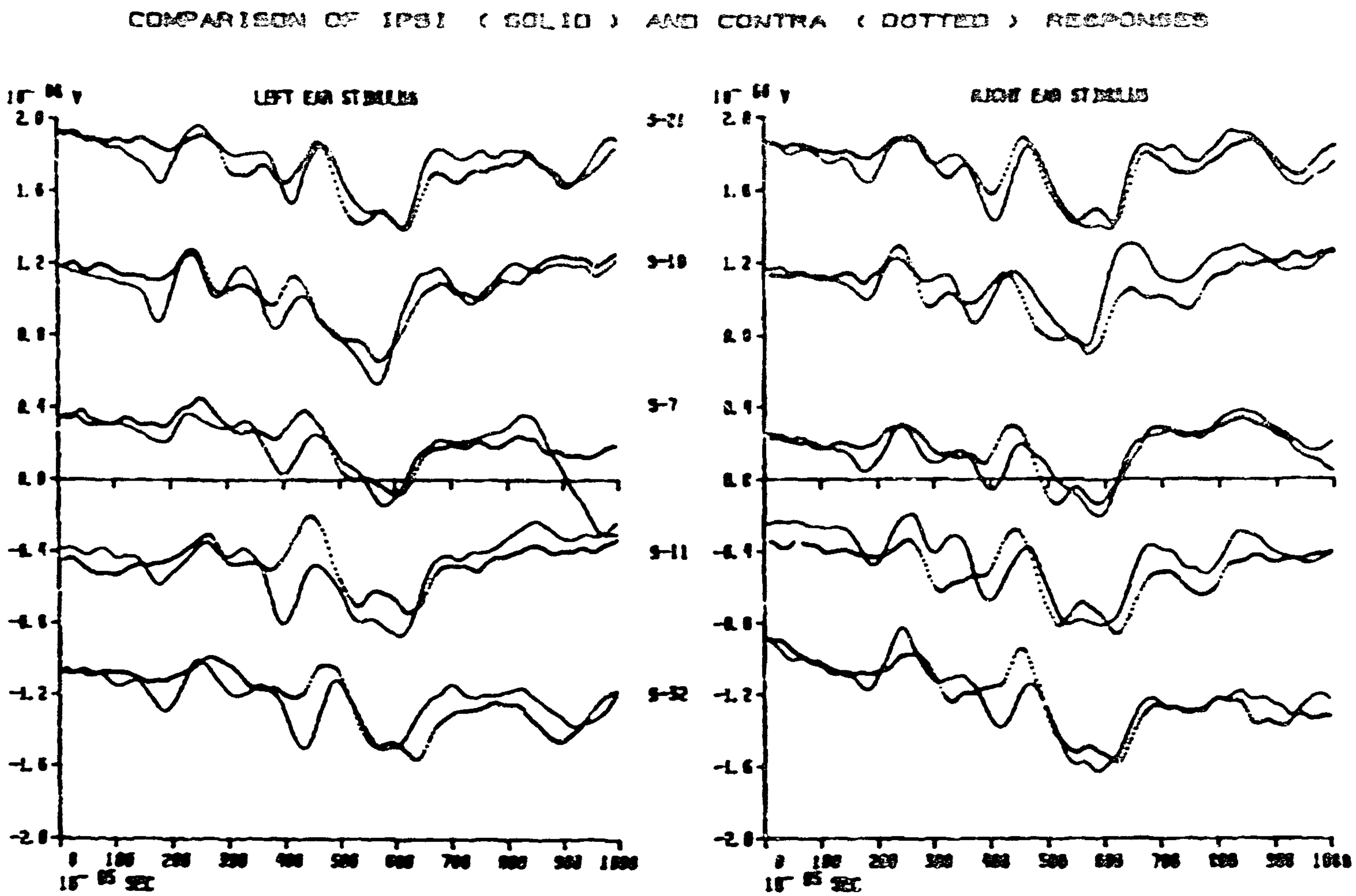


Figure 12

Comparison of simultaneously recorded ipsilateral and contralateral brainstem records from six different subjects based upon 80 dB SL monaural stimulation.

ear stimulus record for this subject best illustrates the general trend for the ipsilaterally recorded Wave II to precede the same contralateral wave. The remaining subject records illustrate variations on the same general points, including the virtual absence of Wave I-N in the contralateral recordings.

These differences in the ipsilateral and contralateral responses for different brainstem waves quantitatively reflect the latency differences observed by Picton et al. (18) when comparing vertex-ipsilateral mastoid recordings to various other electrode configurations. The findings also support in part the work of Zerlin and Naunton (42) who described the delay of Wave III in the ipsilateral recordings and considered that this difference supported the findings of Buchwald and Huang (3) in cat that Wave III is generated at the superior olivary complex. Their finding that Waves IV and V occurred simultaneously in the ipsilateral and contralateral recordings was validated for only Wave IV in the present study. The delay of Wave V-N found in the contralateral recordings, though small, was found to be statistically significant for the population of our study.

At this point, it is difficult to develop an argument that some of these wave latency differences in our study arose from the configuration of the brainstem measurement system. That is, when the left ear was being stimulated, one recording channel measured the potential difference between the vertex and left ear mastoid (identified as the ipsilateral response) and the other channel measured the potential difference between the vertex and right ear mastoid (identified as the contralateral response). To stimulate the right ear, the same headset was moved to the right ear and the recording channels left unchanged. Air-conducted acoustic click crossover was minimized by the ear plug and dummy headset used on the contralateral ear. Bone-conducted acoustic crossover would be present but at a minimal level. Thus the ipsilateral channel for left-ear stimulation became the contralateral channel for right-ear stimulation. A related point involves the symmetry of the surface electrodes relative to the two recording channels. If a nonsymmetrical (anatomical or electrical) placement of the electrodes were utilized, then it might be possible to attribute the ipsilateral/contralateral differences to this factor. However, this is difficult to reconcile in that the two simultaneously recorded brainstem responses were recorded between each mastoid and the vertex with a forehead electrode serving as the ground. Although the forehead electrode cannot at all be considered as an indifferent reference, it is difficult to postulate that this factor could account for both the <u>lead</u> of Waves I-P, II-N, II-P, and V-P and the <u>lag</u> of Wave III in the ipsilateral recordings as compared to the contralateral recordings regardless of the ear stimulated. At this point, it is considered sufficient to present these findings for further validation with the hope that a neurological explanation can be postulated in the future. The findings certainly raise questions relative to the conclusions of Van Olphen, Rodenburg, and Verwey (38) that no electrode positions can be found to identify differences in response to ipsilateral and contralateral stimulation.

Further insight into the nature of these differences is afforded by the transmission time data presented in Table III. Again, the contralateral

Wave III response is shorter than the transmission time of the ipsilateral response. However, the only brainstem wave in the ipsilateral recordings which has a significantly shorter transmission time than its contralateral counterpart is Wave III-N. It should be noted that since the measurement of transmission time depends on the existence of Wave I-N, and since Wave I-N has a low incidence in the contralateral recordings, the t-test statistics for this measure are derived from relatively few data points. The half-period data of Table III indicate that the durations of Waves II and III are greater in the ipsilateral recordings. The converse is true for Wave IV. For the peak-to-peak amplitude comparisons, the ipsilateral responses were significantly greater for Waves I, II, III, and V. As with the half-period data, however, the Wave IV amplitude was greatest in the contralateral recordings. Referring to Figure 7, it is apparent that the incidence of Wave IV was also greatest in the contralateral recordings. It was a general observation that if a slight notch or dip was detected in the negative slope creating Wave V-N in the ipsilateral recordings for a given subject, then the same subject would generally have a recognizable Wave IV in the contralateral recordings. This observation is typified by the Wave IV response of Subject S-7 in Figure 12. Whenever Wave IV was clearly present in the ipsilateral recordings, it was generally present and of larger magnitude in the contralateral recordings.

BRAINSTEM WAVE CORRELATION MATRICES

To gain some possible insight into relationships existing among the individual brainstem waves, both within and across the four brainstem measurement parameters, an extensive series of correlation matrices was constructed and tabulated in Appendices C through F. These matrices, based upon the Pearson product-moment coefficient of correlation, are intended to provide normative baseline relationships for this young population which can be compared to corresponding data to be collected in the future for older populations. The data used in the calculations are based on the responses of the entire subject group to the 80 dB SL stimulus level. Each element of the correlation matrix lists both the coefficient of correlation and the number of data pairs utilized to calculate the coefficient. Whenever the number of data pairs was less than five, the correlation coefficient was not calculated. The unity-value principal diagonal coefficient is listed, when appropriate, to indicate the number of data values available for each waveform measurement.

The correlation matrices presented in Tables C I through C IV describe the intracorrelations between the ipsilaterally recorded brainstem waves for the latency, transmission time, half-period, and peak-to-peak amplitude measurements, respectively. The matrices in Appendix D are also based on the ipsilateral brainstem data but provide intercorrelations between the different measurements for each of the individual waves; for example, Table D I describes the correlations between the latency and transmission time measurements, Table D II pertains to the correlations between the latency and half-period measurements, et cetera. Appendix E, also based upon the ipsilateral data, contains matrices that describe the correlations between measurement data derived from left-ear stimulation and corresponding data derived from right-ear stimulation for all four of the brainstem measurement

parameters. In Appendix F, matrices are presented that describe the correlations between the ipsilateral and contralateral responses for each of the measurement parameters.

The authors recognize that the extensive analysis or interpretation of these correlation matrices at this phase of the project is far beyond the intended scope of the present paper. Since little is known at the present time about correlations that may or should exist between and across the brainstem waves and their different measurement parameters, it is felt that the matrix data will be of value primarily as reference material for future brainstem investigations. In this light, only a few cursory comments will be made relative to the correlation data presented in the appendices, with emphasis placed primarily on the trend or direction rather than the actual magnitude of the coefficients.

First reference will be made to Table C I which tabulates the correlations between the twelve brainstem wave latency measures derived from the ipsilateral recordings made at 80 dB SL. It is emphasized that for a given brainstem wave component, the maximum number of latency measurements available for correlation with another wave component is signified by the number beneath the unity-value correlation coefficient listed for the given component. As denoted by the asterisk symbols in Table C II, there were thirteen correlations between the brainstem wave latencies that were significant to the .001 level or greater, and seven that were significant to only the .01 level. A first observation is that for all six brainstem waves, the latency of the positive terminating peak of a wave was always significantly correlated with its preceding negative peak component; i.e., significant correlations existed between the latency of I-P and the latency of I-N, between II-P and II-N, etc., through VI-P and VI-N. Furthermore, the early waves were linked such that the latency of the initial negative peak of a given wave was correlated (significantly) with the latency of the positive peak of the immediately preceding wave; i.e., Wave II-N was correlated with Wave I-P and Wave III-N with Wave II-P. In the case of Wave III, the positive component was correlated with all preceding wave components, and the negative component with all but the activating VIIIth nerve potential represented by Wave I-N. The principal brainstem wave component, Wave V-N, was found to be correlated with the latency of both components of Wave III and the positive component of Wave II. A point significant to the use of the latency of Wave V as a measure of audiometric threshold is that this wave was not correlated with the latency of Wave I-N (the equivalent of the N1 potential of electrocochleography). Thornton (reference 36-Table III) also found no correlation between the latencies of these two waves (his N1 and N4) based upon 80 dB SL stimuli and six subjects. However, he did find significant correlations present under his 60, 70, and 90 dB SL stimulus conditions. No significant latency correlations were found for Waves IV or VI other than between their negative and positive peak latencies. The actual magnitude of the correlations found to be significant was greatest, in general, for the correlations that existed between the positive and negative components of a given wave.

The correlation matrix for the brainstem transmission time variable is presented in Table C II. In this matrix, there were fourteen correlations significant to the .001 level and five significant to only the .01 level.

The correlation relationships followed, in general, those present with the latency data. It should be noted that since the transmission time of a given wave component uses the latency of Wave I-N as the zero measurement reference, the column labeled as I-N in this table corresponds to the correlation between the latency of Wave I-N and the transmission time of the individual brainstem waves listed in row order below. A general conclusion to be gained from this column is that although the latency of Wave I-N is significantly correlated with the transmission time of only Wave components I-P, II-P, and III-N, the correlation coefficient is in the negative sense for all eleven following components. That is, an increase of the latency of Wave I-N tends to decrease the transmission time of the following waves. In the case of the transmission time of Wave V-N, significant correlations existed with Wave II-P and both components of Wave III.

For the Table C III half-period correlation matrix, the only correlation found significant was between the measurements for Waves I and III. This correlation, in the negative direction, would indicate that an increase in the duration of Wave I is reflected by a decrease in the period or duration of Wave III. The correlations between Wave I and the remaining waves, though not statistically significant, reflect the same negative trend. For the Table C IV peak-to-peak amplitude matrix, no significant correlations were detected except between Waves III and V; i.e., a large Wave III is generally followed by a large Wave V. Thornton (reference 36-Table IV) also found relatively few significant correlations across the response amplitudes for the individual waves.

To assist in the interpretation of the correlations that exist across the four brainstem response measurement parameters and between the individual brainstem waves, the data present in the principal diagonals of the six intercorrelation matrices presented in Appendix D have been extracted and tabulated in Table IV. These extracted data describe, for each individual wave or wave component, the correlations that exist between all possible pairs of the four brainstem measurement parameters. As before, these data are based upon ipsilateral recordings made at the 80 dB SL stimulus level. The latency versus transmission time data of Table IV indicate that these measurements were significantly correlated to a relatively high degree in the positive direction for all of the brainstem wave components. That is, an increase in latency was generally accompanied by an increase in transmission time for each wave. The magnitude of the correlation coefficients was greatest for the subsequent waves; i.e., Waves IV through VI. As shown by the complete matrix in Table D I, the significant correlations that are present between these two measurement parameters fall near the principal diagonal with only few exceptions. Generally, the two measurements were significantly correlated for both components of a given wave. The transmission time of Wave V-N was significantly correlated with the latency of Wave III as well as its own latency. This table also reflects the negative sense of the correlations between the latency of Wave I-N and the transmission time of the following waves.

The latency versus half-period data of Table IV indicate that significant correlations between these two measures were present for the negative and positive components of Wave I, the negative component of Wave II, and the

Table IV

Intercorrelations between ipsilateral latency, transmission time, half-period, and peak-to-peak amplitude measurements for the individual brainstem wave components based upon 80 dB SL stimuli levels and 70 ears. These data were extracted as the principal diagonal from the inter-correlation matrices presented in Appendix D.

IPSILATERAL DATA INTERCORRELATION VARIABLES		INDIVIDUAL BRAINSTEM WAVES I-N	I-P	II-N	II-P	III-N	III-P	IV-N	IV-P	V-N	V-P	VI-N	VI-P
1. Latency	(r)	—	.75***	.75***	.77***	.77***	.79***	.92***	.93***	.86***	.92***	.97***	.98***
2. Transmission Time	(n)	—	66	51	58	66	63	22	21	67	48	36	45
1. Latency	(r)	-.35**	.75***	-.43**	.25	-.13	.46***	.09	.39	-.18	.74***	.05	.67***
2. Half-Period	(n)	66	66	51	51	66	66	21	21	50	50	28	28
1. Latency	(r)	-.14	.12	-.17	.21	-.30	-.28	.06	.29	-.38**	-.37**	-.01	.41
2. P-P Amplitude	(n)	66	66	51	51	66	66	21	21	50	50	28	28
1. Transmission Time	(r)	—	—	-.29	.42**	-.30	.31	.07	.36	-.20	.71***	-.01	.66***
2. Half-Period	(n)	—	—	50	50	63	63	21	21	48	48	27	27
1. Transmission Time	(r)	—	.22	-.23	.15	-.23	-.24	[illegible]	.25	-.39**	-.40**	-.02	.43
2. P-P Amplitude	(n)	—	66	50	50	63	63	21	21	48	48	27	27
1. Half-Period	(r)	.22		.54***		-.02		.79***		-.12		.66***	
2. P-P Amplitude	(n)	66		51		66		21		50		28	

(r) = Pearson product-moment coefficient of correlation.
(n) = Number to data pairs used to calculate (r).
** Significant beyond the .01 level.
*** Significant beyond the .001 level.

positive components of Waves III, V, and VI. The correlations for Wave I-N and II-N were in the negative direction, indicating a decrease in the duration of the waves with an increase in wave latency. The positive sense of the correlations observed for the other wave components implies an increase of wave period or duration with an increase in latency. Examination of the complete matrix in Table D II indicates that no significant correlations exist outside of those along the principal diagonal.

In the case of the latency versus peak-to-peak amplitude data of Table IV, significant correlations were achieved only for the components of Wave V. The negative sense of these two correlations indicates that a decrease in amplitude is generally accompanied by an increase in latency for Wave V. Thornton (reference 35-Table IV) showed significant negative correlations for Wave N4 (our V-N) as well as Wave N5 (our VI-N) using 80 dB SL stimuli. However, at 70 and 90 dB SL, only Wave III was found to be significantly correlated in the same negative direction. The complete matrix in Table D-III shows that the only other significant correlations present involved the latency of Wave V and the peak-to-peak amplitude of Wave III. These correlation coefficients too were negative, implying that an increase of the Wave III amplitude results in the shortening of the Wave V latency.

The transmission time versus half-period data of Table IV show significant correlations for only the positive components of Waves II, V, and VI. For these components, the coefficients signify an increase of transmission time with an increase of wave duration. As indicated by the complete matrix in Table D IV, few significant correlations existed across the brainstem waves for these two measurements. Most predominant were the correlations between the period of Wave I and the early brainstem wave components. The transmission times of both components of Wave II and the negative component of Wave III were significantly correlated in the positive direction with the half-period or duration of Wave I. That is, an increase in the duration of Wave I tends to increase the transmission time of these following waves. However, significant correlations between the half-period of Wave I and the later waves did not result. It should be noted that the unity-valued correlation coefficient associated with the half-period of Wave I and the transmission time of Wave I-P is not significant in the true sense because the transmission time of Wave I-P is, by definition, the half-period of Wave I.

Few significant correlations existed between the transmission time and peak-to-peak amplitude data of Table IV. For only Wave V was there any relationship, and this occurred in the negative direction as did the latency versus peak-to-peak amplitude correlations for this wave. The complete matrix tabulated in Table D V also indicates a negative correlation between the transmission time of Wave V and the peak-to-peak amplitude of Wave III which, again, was reflected in the latency versus peak-to-peak amplitude correlations.

As may be gained from an examination of Table D VI, the only significant correlations present between the half-period and peak-to-peak amplitude data were those present along the principal diagonal as listed in Table IV. That is, significant correlations between these two measurements occurred for Waves II, IV and VI. These correlations, in the positive direction, imply

that an increase in duration of these waves is generally accompanied by an increase in amplitude.

Table V is identical to Table IV, with the exception that the intercorrelations listed pertain to the contralateral responses produced by the 60 dB SL stimulus level. (The complete correlation matrices from which these principal diagonal components were extracted are not incorporated into the report.) Since the transmission time measurement requires the measurement of the latency of Wave I-N, and since the incidence of this wave was relatively low in the contralateral recordings, the number of data values available for correlation of this measurement parameter with the other parameters is relatively low. The vast majority of the correlations found to be statistically significant center on the latency versus transmission time and latency versus half-period measurement pairs. For the latency versus transmission time data, the waves that were found to be significantly correlated in the corresponding Table IV ipsilateral data, with the exception of Wave II and the negative component of Wave III, were found to be significantly correlated in the contralateral data. With the exception of Wave II, the same relationship existed for the latency versus half-period correlations. The only other correlation found to be statistically significant in the remaining measurement-pairs of Table V involved the positive correlation between the half-period and peak-to-peak amplitude of Wave IV. The lack of significant correlations between the contralateral latency and amplitude data of our study for any of the brainstem waves is contrary to the findings of Thornton (reference 35-Table IV) who identified several waves with significant correlations in the negative direction.

In the previous section, differences between the means of the ipsilateral brainstem measures derived from left and right ear stimulation were presented and discussed. In Appendix E, correlation matrices are presented that describe the relationships that existed between and among the different ipsilateral brainstem waves separately produced by left-and right-ear stimulation for each of the four brainstem measurement parameters. The principal diagonals from these Appendix E matrices have been extracted and listed in Table VI. The latency correlation matrix presented in Table E I indicates that the majority of the significant correlations occurred along the principal diagonal. As indicated in Table VI, these correlations were all in the positive sense; i.e., when the latency of a given ipsilateral wave produced by left-ear stimulation was relatively long, the latency of the corresponding wave produced by right-ear stimulation would also be relatively long. The latencies of the negative components of all following waves, with the exception of Wave VI, were all significantly correlated. For the positive components, significant correlations between the ears were observed for only Waves I and III. It should be noted that the latency of Wave I-N was not correlated across ears. Although this special subject group probably had a much better "matched-set" of ears than a group drawn from an unselected population of the same age range, this lack of correlation for Wave I-N probably reflects the independence of the sensitivities of the two ears for a given subject.

In the case of the transmission time measurements, it would be expected that correlations should exist between those left- and right-ear brainstem

Table V

Intercorrelations between contralateral latency, transmission time, half-period, and peak-to-peak amplitude measurements for the individual brainstem wave components based upon 80 dB SL stimuli levels and 70 ears.

CONTRALATERAL DATA INTERCORRELATION VARIABLES		INDIVIDUAL BRAINSTEM WAVES											
		I-N	I-P	II-N	II-P	III-N	III-P	IV-N	IV-P	V-N	V-P	VI-N	VI-P
1. Latency	(r)	—	.69**	.70	.53	.69	.70**	.75	.82**	.81***	.68***	.93**	.97**
2. Transmission Time	(n)	—	13	10	11	10	13	9	9	13	11	7	6
1. Latency	(r)	.09	.69**	-.18	.45	-.26	.38**	-.03	.36	-.11	.79***	.29	.78***
2. Half-Period	(n)	13	13	25	25	47	47	36	36	42	42	17	17
1. Latency	(r)	.19	.35	-.02	.06	-.36	-.14	.05	.32	-.25	-.05	.06	.23
2. P-P Amplitude	(n)	13	13	25	25	47	47	36	36	42	42	17	17
1. Transmission Time	(r)	—	—	-.32	.37	-.05	.57	.003	.61	-.24	.63	NC	NC
2. Half-Period	(n)	—	—	9	9	10	10	8	8	11	11	4	4
1. Transmission Time	(r)	.19	.34	-.11	-.27	-.22	.23	.18	.72	.11	.59	NC	NC
2. P-P Amplitude	(n)	13	13	9	9	10	10	8	8	11	11	4	4
1. Half-Period	(r)	.34		.13		.33		.73***		.12		.33	
2. P-P Amplitude	(n)	13		25		47		36		42		17	

(r) = Pearson product-moment coefficient of correlation.
(n) = Number of data pairs used to calculate (r).
** Significant beyond the .01 level.
*** Significant beyond the .001 level.

NC = Not Calculated, $n < 5$

Table VI

Correlations between the ipsilateral left ear brainstem wave components and the ipsilateral right ear brainstem wave components for the latency, transmission time, half-period, and peak-to-peak amplitude measurements based upon 80 dB SL stimuli and 35 subjects. These data were extracted as the principal diagonal from the Appendix E correlation matrices.

LEFT EAR-RIGHT EAR CORRELATION VARIABLES		INDIVIDUAL BRAINSTEM WAVES											
		I-N	I-P	II-N	II-P	III-N	III-P	IV-N	IV-P	V-N	V-P	VI-N	VI-P
Latency	(r)	.34	.67***	.81***	.47	.74***	.65***	.96**	.91	.76***	.46	.68	.03
	(n)	32	34	22	26	34	32	5	5	35	21	11	18
Transmission Time	(r)	---	.26	.48	.12	.46**	.58***	.63	.62	.69***	.52	.76**	.22
	(n)	---	32	22	26	31	29	5	5	32	19	10	15
Half-Period	(r)	.26		.37		-.28		-.65		.38		.88	
	(n)	32		21		32		5		21		6	
P-P Amplitude	(r)	.50**		.22		.80***		-.58		.91***		.91	
	(n)	32		21		32		5		21		6	

(r) = Pearson product-moment coefficient of correlation
(n) = Number of data pairs used to calculate (r)
** Significant beyond the .01 level
*** Significant beyond the .001 level

waves that evolve from some common neural pathway or transmission route. That is, the correlations should increase for the brainstem waves most remote from their Wave I-N peripheral origin. As indicated by the Table E II transmission time correlation matrix, significant correlations did not arise until Wave III. The principal diagonal of Table E II, listed in Table VI, shows that the transmission times of only Waves III-N, III-P, and V-N were intracorrelated across ears. Table E II also indicates the presence of an unexpected unidirectional correlation between the transmission times of Waves III and V-N. That is, the transmission time of Wave V-N as produced by right-ear stimulation was significantly correlated with the transmission times of Waves III-N and III-P as produced by left-ear stimulation. The converse, however, was not true even though the number of data pairs used in the two sets of calculations was approximately the same. If this difference is not due to random statistical error, then no explanation can be offered for the observation at this time.

In the case of the Table E III half-period correlation matrix, no significant left/right ear correlations were observed between or among the six brainstem waves. For the peak-to-peak amplitude data presented in Table E IV, significant correlations between the left and right ears along the principal diagonal were found for Waves I, III and V. Unidirectional correlations were also present between the amplitude of the left-ear Wave III and the right-ear Wave I; and the left-ear Wave V and the right-ear Wave III.

In a previous section of this report, data were presented that identified statistically significant differences between the means of the ipsilateral and contralateral brainstem measurements for certain of the wave components. The correlation matrices presented in Appendix F are intended to identify statistically significant relationships that may have existed between the same ipsilateral and contralateral brainstem measurements. As before, the principal diagonal of each matrix in Appendix F has been extracted and separately listed in Table VII. The ipsilateral data set derives from combining the ipsilateral responses produced by both left and right ear stimulation. The same applied to the contralateral data set.

A cursory examination of the Appendix F correlation matrices will show that the majority of the significant correlations observed between the ipsilateral and contralateral responses occurred within the Table F I latency matrix. As indicated in Table VII, the ipsilateral and contralateral latency measurements were significantly correlated for all brainstem waves, with the exceptions of I-N and both components of Wave VI. The level of the significant correlations present in the latency matrix was, in general, greatest along the principal diagonal. Inspection of the ipsilateral wave components listed in row order in Table F I shows that the latencies of both components of Waves II and III were significantly correlated with the latencies of almost all of the contralateral waves covering the Wave I-P through V-N range. The converse statement, viz., that both components of the contralateral Waves II and III were significantly correlated with the ipsilateral waves ranging from Wave I-P through V-N, is not true. In effect, unidirectional correlations are present. Examination of the symmetry of the significant correlations within the matrix indicates that for Waves II and III, the correlations are bidirectional and extend between the two waves. For

Table VII

Correlations between the ipsilateral and contralateral brainstem wave components for the latency, transmission time, half-period, and peak-to-peak amplitude measurements based upon 80 dB SL stimuli and 70 ears. These data were extracted as the principal diagonal from the Appendix F correlation matrices.

IPSILATERAL-CONTRALATERAL CORRELATION VARIABLES		INDIVIDUAL BRAINSTEM WAVES I-N	I-P	II-N	II-P	III-N	III-P	IV-N	IV-P	V-N	V-P	VI-N	VI-P
Latency	(r)	.38	.37**	.72***	.73***	.85***	.72***	.77***	.91***	.80***	.83***	.47	.01
	(n)	12	56	31	30	46	64	17	15	69	33	20	26
Transmission Time	(r)	—	-.37	.59	.04	.37	.24	NC	NC	.87***	.70	.04	NC
	(n)	—	12	9	10	10	12	2	1	12	8	6	4
Half-Period	(r)	-.37		.44		.07		.45		.69***		-.11	
	(n)	12		22		44		15		33		10	
P-P Amplitude	(r)	.28		.43		.90***		.28		.37		.59	
	(n)	12		22		44		15		33		10	

(r) = Pearson product-moment coefficient of correlation
(n) = Number of data pairs used to calculate (r)
** Significant beyond the .01 level
*** Significant beyond the .001 level

NC = Not Calculated, n < 5

example, the latency of the ipsilateral Wave III-N is significantly correlated with the latency of the contralateral Wave II-N, and the contralateral Wave III-N is significantly correlated with the ipsilateral Wave II-N. This symmetry is not at all observed for Wave IV. The latency of the negative component of the contralateral Wave IV is significantly correlated with the latency of all ipsilateral wave components ranging from I-N through IV-P. The same relationship exists for the contralateral Wave IV-P which is significantly correlated with all ipsilateral wave components ranging from I-P through V-P. The converse is not true for the latency of the ipsilateral Wave IV components. For Wave V, the majority of the significant correlations have the bidirectional character of those identified with Waves II and III. However, the contralateral Wave V-N is significantly correlated with both components of ipsilateral Waves II and III, while the ipsilateral Wave V-N is correlated with the contralateral Wave III, but not the contralateral Wave II.

It is possible that the unidirectional nature of the Wave IV latency correlations is due to statistical errors arising from the small n associated with the contralateral data, particularly for the early waves. If this is not the case, one is confronted with the following observations: Wave IV is present in both ipsilateral and contralateral recordings, but its incidence is greater in the latter. The amplitude of Wave IV, when present, is generally greatest in the contralateral recordings. The latency of the initial negative component of Wave IV observed in the ipsilateral recordings is highly correlated with the same component in the contralateral recordings as indicated in Table VII. The same applies to the positive component, Wave IV-P, with the degree of correlation even greater than that found for IV-N. Lastly, the latency of the contralateral Wave IV was significantly correlated with almost all of the preceding ipsilateral wave components. The latency of the smaller magnitude ipsilateral Wave IV was only correlated with its contralateral counterpart. In this respect, it seems that the contralateral Wave IV is more closely allied with the brainstem events occurring in the ipsilateral channel. The bidirectional correlations observed between the ipsilateral and contralateral recordings for Waves II, III, and V would imply that these waves are one and the same in both forms of records. The unidirectional nature of the correlations between the ipsilateral and contralateral Wave IV recordings would possibly imply that the observed waves are not of the same origin.

The transmission time correlation matrix presented in Table F II indicates few significant correlations between the ipsilateral and contralateral brainstem wave measurements. Again, because the transmission time variable requires the presence of Wave I-N, and because Wave I-N has low incidence in the contralateral recordings, this matrix is based on relatively small n values. The same form of unidirectional correlation response just described for Wave IV is present for Wave V-N. In this case, the transmission time of the ipsilateral Wave V-N is significantly correlated with the transmission times of contralateral Waves II and III-P. As indicated in Table VII, Wave V-N is the only brainstem wave for which a significant transmission time correlation was obtained between the ipsilateral and contralateral recordings.

Similarly, few significant correlations were observed in the Table F III half-period correlation matrix. Again, Wave V is the only brainstem wave for which a significant half-period correlation was obtained between the ipsilateral and contralateral recordings. The only other significant correlation present in the half-period matrix involved the contralateral Wave II and the ipsilateral Wave I. The negative sense of this correlation implies that an increase in the latency of the ipsilateral Wave I generally results in a shortening of the interval between the peaks of the contralateral Wave II.

In the case of the peak-to-peak amplitude correlation matrix presented in Table F IV, the only significant correlation that occurred along the principal diagonal involved Wave III. This correlation implies that Wave III is the only brainstem wave that consistently displays the same amplitude responses in both the ipsilateral and contralateral recordings. The amplitude of the contralateral Wave III was also correlated in the positive sense with the amplitudes of Waves I and V in the ipsilateral recordings. In addition, the amplitude of the ipsilateral Wave V was negatively correlated with the amplitude of the contralateral Wave II.

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APPENDIX A

Statistical summary of ipsilateral response measurements for each of the individual brainstem evoked response wave components. The data are based upon 4000-sample time-averaged responses of 70 ears to 40, 60, and 80 dB SL acoustic click stimuli presented at a 21 Hz repetition rate.

A I. Latency Measurements
A II. Transmission Time Measurements
A III. Half-Period Measurements
A IV. Peak-to-Peak Amplitude Measurements

Table A I

Basic Ipsilateral Latency Statistics for the Individual Brainstem Wave Components as a Function of Stimulus Level

LATENCY STATISTICS FOR IPSILATERAL RECORDINGS (Milliseconds)										
WAVE	dB-SL	MEAN	MEDIAN	MIN	MAX	RANGE	STD-DEV	STD-ERR	N-Numeric	N-Percent
I-N	80	1.33	1.33	1.05	1.56	.51	.092	.011	67	95.7
	60	1.65	1.64	1.33	2.19	.86	.169	.026	44	62.9
	40	2.36	2.42	1.84	2.81	.98	.309	.089	12	17.1
I-P	80	1.97	1.95	1.60	2.30	.70	.132	.016	69	98.6
	60	2.18	2.13	1.87	2.50	.62	.166	.026	40	57.1
	40	2.82	3.01	2.19	3.32	1.13	.391	.130	9	12.9
II-N	80	2.50	2.50	2.23	2.81	.60	.142	.020	52	74.3
	60	2.70	2.69	2.38	3.09	.70	.196	.034	34	40.6
	40	2.93	NC	NC	NC	NC	NC	NC	4	5.7
II-P	80	2.93	2.97	2.62	3.20	.59	.133	.017	59	84.3
	60	3.44	3.16	2.85	3.44	.59	.141	.021	45	64.3
	40	3.64	3.63	2.89	4.14	1.25	.415	.138	9	12.9
III-N	80	3.58	3.55	3.24	3.87	.62	.133	.016	69	98.6
	60	3.78	3.79	3.36	4.18	.82	.179	.024	57	81.4
	40	4.54	4.57	3.71	5.12	1.41	.262	.050	27	38.6
III-P	80	4.17	4.18	3.75	4.45	.70	.145	.018	66	94.3
	60	4.40	4.38	3.91	4.96	1.06	.197	.027	53	75.7
	40	5.17	5.19	4.02	5.90	1.87	.347	.063	30	42.9
IV-N	80	4.91	4.91	4.65	5.19	.55	.157	.033	22	31.4
	60	5.02	5.08	4.57	5.35	.78	.244	.068	13	18.6
	40	5.79	NC	NC	NC	NC	NC	NC	3	4.3
IV-P	80	5.14	5.16	4.88	5.47	.59	.170	.037	21	30.0
	60	5.25	5.27	5.00	5.55	.55	.179	.042	18	25.7
	40	5.99	NC	NC	NC	NC	NC	NC	3	4.3
V-N	80	5.47	5.47	5.08	5.90	.82	.170	.020	70	100.0
	60	5.75	5.74	5.16	6.21	1.05	.216	.026	68	97.1
	40	6.38	6.41	5.54	7.03	1.48	.284	.035	67	95.7
V-P	80	6.31	6.33	5.90	6.95	1.06	.241	.034	50	71.4
	60	6.67	6.60	6.05	7.42	1.37	.351	.056	39	55.7
	40	7.49	7.54	6.87	8.08	1.21	.389	.075	27	38.6
VI-N	80	7.00	7.03	6.44	7.58	1.13	.325	.053	37	52.9
	60	7.36	7.38	6.91	7.85	.94	.234	.044	28	40.0
	40	8.19	8.16	7.62	8.98	1.37	.343	.089	15	21.4
VI-P	80	7.76	7.89	6.64	8.32	1.68	.405	.059	48	68.6
	60	8.21	8.28	7.38	9.10	1.72	.368	.061	36	51.4
	40	8.46	8.59	7.62	8.91	1.29	.367	.102	13	18.6

NC = Not Calculated, N < 5

Table A II

Basic Ipsilateral Transmission Time Statistics for the Individual Brainstem Wave Components as a Function of Stimulus Level

TRANSMISSION TIME STATISTICS FOR IPSILATERAL RECORDINGS (Milliseconds)										
WAVE	dB-SL	MEAN	MEDIAN	MIN	MAX	RANGE	STD-DEV	STD-ERR	N-Numeric	N-Percent
I-P	80	.64	.63	.35	1.05	.70	.130	.016	66	94.3
	60	.55	.59	.27	.74	.47	.130	.023	33	47.1
	40	.54	.55	.35	.66	.31	.112	.046	6	8.6
II-N	80	1.17	1.17	.94	1.60	.66	.129	.018	51	72.9
	60	1.07	1.05	.74	1.56	.82	.178	.034	28	40.0
	40	.96	NC	NC	NC	NC	NC	NC	2	2.9
II-P	80	1.60	1.60	1.25	1.84	.59	[illegible]	.018	58	82.9
	60	1.51	1.52	1.25	1.84	.59	[illegible]	.028	32	45.7
	40	1.34	1.33	1.05	1.60	.55	.212	[illegible]	5	7.1
III-N	80	2.24	2.27	1.87	2.50	.63	.140	.017	66	94.3
	60	2.13	2.15	1.76	2.38	.63	.153	.024	39	55.7
	40	2.10	2.11	1.84	2.50	.66	.213	.071	9	12.9
III-P	80	2.83	2.85	2.46	3.09	.63	.139	.018	63	90.0
	60	2.73	2.69	2.38	3.01	.63	.144	.024	36	51.4
	40	2.78	2.75	2.19	3.09	.90	.281	.089	10	14.3
IV-N	80	3.56	3.55	3.28	3.83	.55	.161	.034	22	31.4
	60	3.27	3.28	2.97	3.51	.55	.210	.074	8	11.4
	40	---	NC	NC	NC	NC	NC	NC	0	0.0
IV-P	80	3.79	3.82	3.52	4.10	.59	.174	.038	21	30.0
	60	3.56	3.59	3.28	3.83	.55	.202	.058	12	17.1
	40	---	NC	NC	NC	NC	NC	NC	0	0.0
V-N	80	4.14	4.14	3.67	4.57	.90	.172	.021	67	95.7
	60	4.05	4.02	3.55	4.65	1.09	.205	.031	44	62.9
	40	3.80	3.71	3.44	4.30	.86	.293	.088	11	15.7
V-P	80	4.97	4.96	4.53	5.47	.94	.233	.034	48	68.6
	60	4.94	4.88	4.41	5.86	1.45	.328	.063	27	38.6
	40	5.04	NC	NC	NC	NC	NC	NC	4	5.7
VI-N	80	5.67	5.68	5.08	6.17	1.09	.327	.054	36	51.4
	60	5.71	5.74	5.19	6.13	.94	.279	.064	19	27.1
	40	5.52	5.58	5.35	5.59	.23	.102	.046	5	7.1
VI-P	80	6.40	6.52	5.31	6.99	1.68	.413	.061	45	64.3
	60	6.53	6.62	5.59	7.15	1.56	.412	.084	24	34.3
	40	6.34	NC	NC	NC	NC	NC	NC	4	5.7

NC = Not Calculated, N < 5

Table A III

Basic Ipsilateral Half-Period Statistics for the Individual Brainstem Wave Components as a Function of Stimulus Level

HALF-PERIOD STATISTICS FOR IPSILATERAL RECORDINGS (Milliseconds)										
WAVE	dB-SL	MEAN	MEDIAN	MIN	MAX	RANGE	STD-DEV	STD-ERR	N-Numeric	N-Percent
I	80	.64	.63	.35	1.05	.70	.130	.016	66	94.3
	60	.55	.59	.27	.74	.47	.130	.023	33	47.1
	40	.54	.55	.35	.66	.31	.112	.046	6	8.6
II	80	.42	.39	.19	.63	.43	.095	.013	51	72.9
	60	.43	.43	.23	.66	.43	.113	.020	32	45.7
	40	.53	NC	NC	NC	NC	NC	NC	4	5.7
III	80	.59	.59	.43	.82	.39	.084	.010	66	94.3
	60	.58	.57	.39	.82	.43	.101	.015	48	68.6
	40	.59	.59	.31	.90	.59	.158	.035	20	28.6
IV	80	.24	.23	.16	.35	.20	.052	.011	21	30.0
	60	.30	.27	.16	.70	.55	.149	.045	11	15.7
	40	.29	NC	NC	NC	NC	NC	NC	2	2.9
V	80	.87	.82	.59	1.52	.94	.208	.029	50	71.4
	60	.94	.90	.62	1.68	1.05	.235	.038	38	54.3
	40	1.13	1.17	.66	1.49	.82	.217	.042	27	38.6
VI	80	.64	.62	.19	1.21	1.01	.291	.055	28	40.0
	60	.86	.94	.23	1.41	1.17	.318	.077	17	24.3
	40	.81	NC	NC	NC	NC	NC	NC	3	4.29

NC = Not Calculated, N < 5

Table A IV

Basic Ipsilateral Peak-to-Peak Amplitude Statistics for the Individual Brainstem Wave Components as a Function of Stimulus Level

PEAK-TO-PEAK AMPLITUDE STATISTICS FOR IPSILATERAL RECORDINGS (Nanovolts)										
WAVE	dB-SL	MEAN	MEDIAN	MIN	MAX	RANGE	STD-DEV	STD-ERR	N-Numeric	N-Percent
I	80	223	223	90	373	283	70.6	8.7	66	94.3
	60	114	121	24	227	203	44.6	7.8	33	47.1
	40	106	104	85	133	49	20.4	8.3	6	8.6
II	80	91	85	14	270	256	46.2	6.5	51	72.9
	60	65	56	10	153	[illegible]	36.1	6.4	32	45.7
	40	99	NC	NC	NC	NC	NC	NC	4	5.7
III	80	255	244	86	667	581	107.4	13.2	66	94.3
	60	141	134	54	246	191	52.7	7.6	48	68.6
	40	109	103	18	214	196	42.6	9.5	20	28.6
IV	80	29	25	7	65	57	17.9	3.9	21	30.0
	60	31	19	8	71	63	22.5	6.5	12	17.1
	40	40	NC	NC	NC	NC	NC	NC	2	2.9
V	80	526	493	219	997	777	160.4	22.7	50	71.4
	60	391	383	83	617	534	108.4	17.6	38	54.3
	40	404	411	249	578	329	88.2	17.0	27	38.6
VI	80	157	133	14	408	395	100.6	19.0	28	40.0
	60	202	208	23	378	356	107.6	26.1	17	24.3
	40	246	NC	NC	NC	NC	NC	NC	3	4.3

NC = Not Calculated, N < 5

APPENDIX B

Statistical summary of contralateral response measurements for each of the individual brainstem evoked response wave components. The data are based upon 4000-sample time-averaged responses of 70 ears to 40, 60, and 80 dB SL acoustic click stimuli presented at a 21 Hz repetition rate.

Table B-1

Basic Contralateral Latency Statistics for the Individual Brainstem Wave Components as a Function of Stimulus Level

LATENCY STATISTICS FOR CONTRALATERAL RECORDINGS (Milliseconds)

WAVE	dB-SL	MEAN	MEDIAN	MIN	MAX	RANGE	STD-DEV	STD-ERR	N-Numeric	N-Percent
I-N	80	1.41	1.41	1.25	1.56	.31	.101	.028	13	18.6
	60	1.68	NC	NC	NC	NC	NC	NC	3	4.3
	40	2.24	2.13	1.91	2.85	.94	.367	.150	6	8.6
I-P	80	2.06	2.07	1.72	2.30	.59	.131	.017	57	81.4
	60	2.25	2.25	1.91	2.69	.78	.182	.036	26	37.1
	40	2.86	2.85	2.27	3.36	1.09	.347	.105	11	15.7
II-N	80	2.66	2.66	2.42	2.89	.47	.119	.021	33	47.1
	60	2.81	2.79	2.50	3.09	.59	.176	.044	16	22.9
	40	3.41	NC	NC	NC	NC	NC	NC	3	4.3
II-P	80	3.05	3.05	2.81	3.40	.58	.131	.023	34	48.6
	60	3.17	3.16	2.85	3.59	.74	.169	.036	22	31.4
	40	3.70	3.81	3.12	4.14	1.02	.416	.170	6	8.6
III-N	80	3.47	3.48	3.16	3.87	.70	.146	.021	47	67.1
	60	3.70	3.71	3.32	4.53	1.21	.223	.036	38	54.3
	40	4.53	4.59	4.29	4.73	.43	.179	.063	8	11.4
III-P	80	3.40	3.98	3.71	4.45	.74	.141	.017	67	95.7
	60	4.23	4.22	3.79	4.84	1.05	.207	.028	55	78.6
	40	5.04	5.04	4.61	5.55	.94	.208	.037	32	45.7
IV-N	80	4.83	4.84	4.53	5.19	.66	.159	.025	40	57.1
	60	5.01	5.02	4.73	5.43	.70	.163	.033	24	34.3
	40	5.92	5.88	5.59	6.48	.90	.264	.083	10	14.3
IV-P	80	5.12	5.12	4.73	5.47	.74	.175	.028	40	57.1
	60	5.33	5.35	4.92	5.70	.78	.206	.038	30	42.9
	40	6.05	6.03	5.12	6.72	1.60	.400	.116	12	17.1
V-N	80	5.58	5.59	5.19	5.90	.70	.172	.021	69	98.6
	60	5.83	5.86	5.39	6.29	.90	.205	.025	69	98.6
	40	6.48	6.44	5.74	7.38	1.64	.303	.039	62	88.6
V-P	80	6.33	6.33	5.94	7.58	1.64	.291	.045	42	60.0
	60	6.79	6.72	6.21	8.00	1.79	.351	.056	39	55.7
	40	7.58	7.60	6.76	8.28	1.52	.368	.069	28	40.0
VI-N	80	7.06	7.07	6.33	8.40	2.15	.436	.080	30	42.8
	60	7.30	7.30	6.44	8.48	2.03	.374	.073	26	37.1
	40	8.01	8.03	7.11	8.51	1.41	.347	.093	14	20.0
VI-P	80	7.71	7.77	6.72	9.02	2.30	.528	.091	34	48.6
	60	8.16	8.22	6.99	9.14	2.15	.598	.106	32	45.7
	40	8.52	8.67	7.07	9.14	2.07	.559	.161	12	17.1

NC = Not Calculated, N < 5

Table B II

Basic Contralateral Transmission Time Statistics for the Individual Brainstem Wave Components as a Function of Stimulus Level

TRANSMISSION TIME STATISTICS FOR CONTRALATERAL RECORDINGS (Milliseconds)										
WAVE	dB-SL	MEAN	MEDIAN	MIN	MAX	RANGE	STD-DEV	STD-DEV	N-Numeric	N-Percent
I-P	80	.58	.59	.39	.70	.31	.088	.024	13	18.6
	60	.63	NC	NC	NC	NC	NC	NC	1	1.4
	40	.49	NC	NC	NC	NC	NC	NC	4	5.7
II-N	80	1.27	1.25	1.13	1.41	.27	.101	.032	10	14.3
	60	1.05	NC	NC	NC	NC	NC	NC	3	4.3
	40	NC	NC	NC	NC	NC	NC	NC	0	0
II-P	80	1.63	1.60	1.52	1.84	.31	.095	.029	11	15.7
	60	1.37	NC	NC	NC	NC	NC	NC	2	2.9
	40	1.50	NC	NC	NC	NC	NC	NC	3	4.3
III-N	80	2.04	2.03	1.87	2.23	.35	.108	.034	10	14.3
	60	1.87	NC	NC	NC	NC	NC	NC	1	1.4
	40	2.03	NC	NC	NC	NC	NC	NC	2	2.9
III-P	80	2.55	2.50	2.38	2.77	.39	.128	.035	13	18.6
	60	2.40	NC	NC	NC	NC	NC	NC	2	2.9
	40	2.66	NC	NC	NC	NC	NC	NC	4	5.7
IV-N	80	3.44	3.44	3.28	3.63	.35	.131	.044	9	12.9
	60	3.22	NC	NC	NC	NC	NC	NC	2	2.9
	40	3.63	NC	NC	NC	NC	NC	NC	2	2.9
IV-P	80	3.66	3.63	3.44	4.02	.59	.177	.059	9	12.9
	60	3.46	NC	NC	NC	NC	NC	NC	2	2.9
	40	3.89	NC	NC	NC	NC	NC	NC	2	2.9
V-N	80	4.10	4.10	3.75	4.37	.63	.167	.046	13	18.6
	60	3.89	NC	NC	NC	NC	NC	NC	3	4.3
	40	4.19	[illegible]	3.75	4.61	.86	.343	.153	5	7.1
V-P	80	4.84	4.84	4.41	5.19	.78	.227	.069	11	15.7
	60	4.61	NC	NC	NC	NC	NC	NC	1	1.4
	40	5.39	NC	NC	NC	NC	NC	NC	1	1.4
VI-N	80	5.23	5.12	4.88	5.70	.82	.32	.120	7	10.0
	60	4.38	NC	NC	NC	NC	NC	NC	2	2.9
	40	5.65	NC	NC	NC	NC	NC	NC	3	4.3
VI-P	80	5.89	5.82	5.39	6.72	1.33	.51	.209	6	8.6
	60	5.27	NC	NC	NC	NC	NC	NC	2	2.9
	40	6.12	NC	NC	NC	NC	NC	NC	4	5.7

NC = Not Calculated, N < 5

Table B III

Basic Contralateral Half-Period Statistics for the Individual Brainstem Waves as a Function of Stimulus Level

HALF-PERIOD STATISTICS FOR CONTRALATERAL RECORDINGS (Milliseconds)										
WAVE	dB-SL	MEAN	MEDIAN	MIN	MAX	RANGE	STD-DEV	STD-ERR	N-Numeric	N-Percent
I	80	.58	.59	.39	.70	.31	.088	.024	13	18.6
	60	.63	NC	NC	NC	NC	NC	NC	1	1.4
	40	.49	NC	NC	NC	NC	NC	NC	4	5.7
II	80	.37	.39	.23	.51	.27	.070	.014	25	35.7
	60	.34	.35	.16	.55	.39	.108	.030	13	18.6
	40	.39	NC	NC	NC	NC	NC	NC	1	1.4
III	80	.54	.55	.31	.78	.47	.096	.014	47	67.1
	60	.51	.51	.31	.74	.43	.115	.020	34	48.6
	40	.50	.49	.31	.74	.43	.163	.066	6	8.6
IV	80	.28	.27	.16	.43	.27	.067	.011	36	51.4
	60	.30	.27	.19	.70	.51	.112	.024	22	31.4
	40	.25	.23	.16	.35	.20	.059	.020	9	12.9
V	80	.78	.70	.51	2.03	1.52	.249	.038	42	60.0
	60	.95	.86	.31	2.11	1.80	.280	.045	39	55.7
	40	1.15	1.19	.59	1.68	1.09	.230	.044	28	40.0
VI	80	.74	.78	.23	1.29	1.05	.293	.071	17	24.3
	60	.75	.74	.23	1.29	1.05	.300	.075	16	22.9
	40	.84	NC	NC	NC	NC	NC	NC	4	5.7

NC = Not Calculated, N < 5

Table B IV

Basic Contralateral Peak-to-Peak Amplitude Statistics for the Individual Brainstem Wave Components as a Function of Stimulus Level

PEAK-TO-PEAK AMPLITUDE STATISTICS FOR CONTRALATERAL RECORDINGS (Nanovolts)										
WAVE	dB-SL	MEAN	MEDIAN	MIN	MAX	RANGE	STD-DEV	STD-ERR	N-Numeric	N-Percent
I	80	133	142	79	197	117	32.8	9.1	13	18.6
	60	93	NC	NC	NC	NC	NC	NC	1	1.4
	40	96	NC	NC	NC	NC	NC	NC	4	5.7
II	80	59	65	10	110	100	28.8	5.8	25	35.7
	60	43	45	14	76	63	16.0	4.4	13	18.6
	40	70	NC	NC	NC	NC	NC	NC	1	1.4
III	80	183	163	42	578	536	98.8	14.4	47	67.1
	60	117	114	37	269	231	48.9	8.4	34	48.6
	40	74	77	46	93	48	19.2	7.9	6	8.6
IV	80	47	37	6	129	123	34.7	5.8	36	51.4
	60	30	19	3	97	93	24.5	5.2	22	31.4
	40	22	22	5	41	36	12.5	4.2	9	12.9
V	80	357	349	71	580	509	109.9	17.0	42	60.0
	60	303	315	103	479	376	96.3	15.4	39	55.7
	40	311	303	147	525	378	103.5	19.6	28	40.0
VI	80	185	177	35	633	598	139.7	33.9	17	24.3
	60	179	171	29	344	314	88.3	22.1	16	22.9
	40	145	NC	NC	NC	NC	NC	NC	4	5.7

NC = Not Calculated, N < 5

APPENDIX C

Intracorrelations between the individual brainstem evoked response wave components for different ipsilateral response measurements. The data are based upon 4000-sample time-averaged responses of 70 ears to 80 dB SL acoustic click stimuli presented at a 21 Hz repetition rate.

C I. Latency vs. Latency
C II. Transmission Time vs. Transmission Time
C III. Half-Period vs. Half-Period
C IV. Peak-to-Peak Amplitude vs. Peak-to-Peak Amplitude

Table C I

Latency Intercorrelations between the Ipsilateral Brainstem Wave Components

LATENCY OF INDIVIDUAL WAVEFORMS - IPSILATERAL DATA

LATENCY OF INDIVIDUAL WAVEFORMS		I-N	I-P	II-N	II-P	III-N	III-P	IV-N	IV-P	V-N	V-P	VI-N	VI-P
I-N	(r)	1.000											
	(n)	67											
I-P	(r)	.368**	1.000										
	(n)	66	69										
II-N	(r)	.459***	.571***	1.000									
	(n)	51	52	57									
II-P	(r)	.283	.390**	.764***	1.000								
	(n)	58	59	51	59								
III-N	(r)	.261	.478***	.369***	.564***	1.000							
	(n)	66	68	52	59	69							
III-P	(r)	.367**	.369**	.513***	.418**	.817***	1.000						
	(n)	63	65	49	56	66	66						
IV-N	(r)	.139	.006	.594	.571	.380	.211	1.000					
	(n)	22	21	14	17	22	21	22					
IV-P	(r)	.132	-.018	.714	.453	.378	.198	.953***	1.000				
	(n)	21	20	14	16	21	20	21	21				
V-N	(r)	.275	.274	.289	.345**	.602***	.478***	.393	.474	1.000			
	(n)	67	69	52	59	69	66	22	21	70			
V-P	(r)	.135	.022	-.116	.030	.407**	.276	.220	.273	.526***	1.000		
	(n)	48	50	38	42	50	47	13	12	50	50		
VI-N	(r)	-.061	.040	.050	-.007	-.120	-.074	.003	.026	.019	.236	1.000	
	(n)	36	37	29	32	37	36	12	11	37	32	37	
VI-P	(r)	.032	-.045	-.123	-.088	.027	.033	.390	.504	.090	.279	.772***	1.000
	(n)	45	47	35	39	48	45	14	13	48	38	28	48

(r) = Pearson product-moment coefficient of correlation
(n) = Number of data pairs used to calculate (r)
** Significant beyond the .01 level
*** Significant beyond the .001 level

Table C II

Transmission Time Intercorrelations between the Ipsilateral [illegible] Wave Components

TRANSMISSION TIME OF INDIVIDUAL WAVEFORMS		I-N	I-P	II-N	II-P	III-N	III-P	IV-N	IV-P	V-N	V-P	VI-N	VI-P
I-N	(r)	1.000											
	(n)	67											
I-P	(r)	-.345**	1.000										
	(n)	66	66										
II-N	(r)	-.243	.521***	1.000									
	(n)	51	51	51									
II-P	(r)	-.386**	.431***	.748***	1.000								
	(n)	58	58	50	58								
III-N	(r)	-.408***	.496***	.532***	.592***	1.000							
	(n)	66	65	51	58	66							
III-P	(r)	-.285	.306	.426**	.398**	.812***	1.000						
	(n)	63	62	48	55	63	63						
IV-N	(r)	-.259	-.107	.601	.604	.403	.234	1.000					
	(n)	22	21	14	17	22	21	22					
IV-P	(r)	-.243	-.128	.723	.318	.401	.267	.955***	1.000				
	(n)	21	20	14	16	21	20	21	21				
V-N	(r)	-.261	.248	.223	.357**	.610***	.464***	.395	.478	1.000			
	(n)	67	66	51	58	66	63	22	21	67			
V-P	(r)	-.267	.068	-.000	.200	.477***	.290	.232	.295	.551***	1.000		
	(n)	48	48	38	42	48	45	13	12	48	48		
VI-N	(r)	-.280	.081	.089	.055	-.068	-.098	.048	.069	.012	.153	1.000	
	(n)	36	36	29	32	36	35	12	11	36	31	36	
VI-P	(r)	-.184	-.013	-.122	-.048	.043	.027	.402	.509	.103	.181	.749***	1.000
	(n)	45	44	34	38	45	42	14	13	45	36	27	45

(r) = Pearson product-moment coefficient of correlation
(n) = Number of data pairs used to calculate (r)
** Significant beyond the .01 level
*** Significant beyond the .001 level

Table C III

Half-Period Intercorrelations between the Ipsilateral Brainstem Waves

HALF-PERIOD OF INDIVIDUAL WAVEFORMS		HALF-PERIOD OF INDIVIDUAL WAVEFORMS - IPSILATERAL DATA I	II	III	IV	V	VI
I	(r)	1.000					
	(n)	66					
II	(r)	-.140	1.000				
	(n)	50	51				
III	(r)	-.383**	-.116	1.000			
	(n)	62	48	66			
IV	(r)	-.016	-.195	-.190	1.000		
	(n)	20	14	20	21		
V	(r)	-.240	.290	-.015	-.083	1.000	
	(n)	48	37	47	12	50	
VI	(r)	-.121	.187	.038	.477	-.005	1.000
	(n)	27	21	27	8	26	28

(r) = Pearson product-moment coefficient of correlation
(n) = Number of data pairs used to calculate (r)
** Significant beyond the .01 level

Table C IV

Peak-to-Peak Amplitude Intracorrelations between the Ipsilateral Brainstem Waves

PEAK-TO-PEAK WAVEFORM AMPLITUDE		PEAK-TO-PEAK AMPLITUDE OF INDIVIDUAL WAVEFORMS - IPSILATERAL DATA					
		I	II	III	IV	V	VI
I	(r)	1.000					
	(n)	66					
II	(r)	.075	1.000				
	(n)	50	51				
III	(r)	.309	-.003	1.000			
	(n)	62	48	66			
IV	(r)	-.115	-.057	-.106	1.000		
	(n)	20	14	20	21		
V	(r)	.154	.044	.491***	-.236	1.000	
	(n)	48	37	47	12	50	
VI	(r)	.151	-.135	.413	.233	.450	1.000
	(n)	27	21	27	8	26	28

(r) = Pearson product-moment coefficient of correlation
(n) = Number of data pairs used to calculate (r)
*** Significant beyond the .001 level

APPENDIX D

Intercorrelations between different ipsilateral response measurements for each of the individual brainstem evoked response wave components. The data are based upon 4000-sample time-averaged responses of 70 ears to 80 dB SL acoustic click stimuli presented at a 21-Hz repetition rate.

- D I. Latency vs. Transmission Time
- D II. Latency vs. Half-Period
- D III. Latency vs. Peak-to-Peak Amplitude
- D IV. Transmission Time vs. Half-Period
- D V. Transmission Time vs. Peak-to-Peak Amplitude
- D VI. Half-Period vs. Peak-to-Peak Amplitude

Table D1 Intercorrelations between Ipsilateral Latency and Ipsilateral Transmission Time of Individual Brainstem Wave Components

TRANSMISSION TIME OF INDIVIDUAL WAVEFORMS		LATENCY OF INDIVIDUAL WAVEFORMS - IPSILATERAL DATA											
		I-N	I-P	II-N	II-P	III-N	III-P	IV-N	IV-P	V-N	V-P	VI-N	VI-P
I-N	(r)	1.000	.368**	.459***	.283	.261	.367**	.139	.132	.275	.135	-.061	.032
	(n)	67	66	51	58	66	63	22	21	67	48	36	45
I-P	(r)	-.345**	.746***	.208	.179	.246	.047	-.095	-.120	.063	-.124	.018	-.116
	(n)	66	66	51	58	65	63	21	20	66	48	36	44
II-N	(r)	-.243	.316	.751***	.593***	.356	.209	.554	.706	.079	-.104	.064	-.181
	(n)	51	51	51	50	51	48	14	14	51	38	29	34
II-P	(r)	-.386**	.159	.426**	.775***	.327	.107	.465	.333	.145	.326	.310	-.106
	(n)	58	58	50	58	58	55	17	16	58	42	32	38
III-N	(r)	-.408***	.206	.220	.346**	.775***	.506***	.303	.304	.391**	.310	-.131	-.039
	(n)	66	65	51	58	66	63	22	21	66	48	36	45
III-P	(r)	-.285	.101	.228	.260	.669***	.787***	.140	.130	.315	.138	-.122	-.037
	(n)	63	62	48	55	63	63	21	20	63	45	35	42
IV-N	(r)	-.299	-.257	.308	.433	.252	.112	.921***	.873***	.281	.280	.039	.387
	(n)	22	21	14	17	22	21	22	21	22	13	12	14
IV-P	(r)	-.243	-.269	.365	.307	.260	.107	.884***	.929***	.369	.327	.058	.487
	(n)	21	20	14	16	21	20	21	21	21	12	11	13
V-N	(r)	-.261	.059	.048	.199	.460***	.269	.344	.428	.856***	.442**	-.008	.053
	(n)	67	66	51	58	66	63	22	21	67	48	36	45
V-P	(r)	-.267	-.121	-.270	-.067	.343	.086	.074	.144	.409**	.919***	.091	.155
	(n)	48	48	38	42	48	45	13	12	48	48	31	36
VI-N	(r)	-.280	-.100	-.030	-.080	-.222	-.237	-.036	-.009	-.111	.063	.975***	.709***
	(n)	36	36	29	32	36	35	12	11	36	31	36	27
VI-P	(r)	-.184	-.148	-.225	-.141	-.069	-.117	.371	.490	.013	.167	.757***	.977***
	(n)	45	44	34	38	45	42	14	13	45	36	27	45

(r) = Pearson product-moment coefficient of correlation
(n) = Number of data pairs used to calculate (r)
** Significant beyond the .01 level
***Significant beyond the .001 level

Table D II

Interconnelations between Ipsilateral Latency and Ipsilateral Half-Period of Individual Brainstem Wave Components

HALF-PERIOD OF INDIVIDUAL WAVEFORMS		LATENCY OF INDIVIDUAL WAVEFORMS - IPSILATERAL DATA											
		I-N	I-P	II-N	II-P	III-N	III-P	IV-N	IV-P	V-N	V-P	VI-N	VI-P
I	(r)	-.345**	.746***	.208	.179	.246	.047	-.095	-.120	.063	-.124	.018	-.116
	(n)	66	66	51	58	65	62	21	20	66	48	36	44
II	(r)	-.223	-.312	-.431**	.253	-.103	-.210	-.090	-.178	-.042	.198	.030	.138
	(n)	50	51	51	51	51	48	14	14	51	37	29	34
III	(r)	.244	-.174	-.001	-.099	-.134	.462***	-.268	-.290	-.066	-.169	.089	.124
	(n)	63	65	49	56	66	66	21	20	66	47	36	45
IV	(r)	.036	.004	.168	-.096	.131	.026	.089	.385	.401	.195	-.121	.054
	(n)	21	20	14	16	21	20	21	21	21	12	11	13
V	(r)	-.057	-.248	-.228	-.151	-.057	-.076	-.505	-.457	-.181	.742***	.302	.249
	(n)	48	50	38	42	50	47	13	12	50	50	32	38
VI	(r)	.175	.010	-.072	-.027	.172	.189	.636	.823	.038	.023	.048	.672***
	(n)	27	28	21	24	28	27	9	8	28	26	28	28

(r) = Pearson product-moment coefficient of correlation
(n) = Number of data pairs used to calculate (r)
** Significant beyond the .01 level
*** Significant beyond the .001 level

Table D III

Intercorrelations between Ipsilateral Latency and Ipsilateral Peak-to-Peak Amplitude of Individual Brainstem Wave Components

PEAK-TO-PEAK WAVEFORM AMPLITUDE		LATENCY OF INDIVIDUAL WAVEFORMS - IPSILATERAL DATA I-N	I-P	II-N	II-P	III-N	III-P	IV-N	IV-P	V-N	V-P	VI-N	VI-P
I	(r)	-.139	.119	.069	.182	-.252	-.216	.106	-.077	-.281	-.341	.065	-.078
	(n)	66	66	51	58	65	62	21	20	66	48	36	44
II	(r)	.071	-.146	-.166	.205	.018	-.105	.195	.081	.095	.243	.088	.170
	(n)	50	51	51	51	51	48	14	14	51	37	29	34
III	(r)	-.081	.012	.158	.026	-.296	-.278	.206	.070	-.416***	-.405**	-.017	-.144
	(n)	63	65	49	56	66	66	21	20	66	47	36	45
IV	(r)	.104	.060	-.051	-.179	-.088	-.169	.059	.293	.177	-.104	.067	.103
	(n)	21	23	14	16	21	20	21	21	21	12	11	13
V	(r)	-.000	-.003	.130	.011	-.282	-.317	-.182	-.240	-.383**	-.367**	.290	.190
	(n)	48	50	38	42	50	47	13	12	50	50	32	38
VI	(r)	.124	.048	.124	-.061	-.075	.013	.466	.632	-.435	-.387	-.015	.407
	(n)	27	28	21	24	28	27	9	8	28	26	28	28

(r) = Pearson product-moment coefficient of correlation
(n) = Number of data pairs used to calculate (r)
** Significant beyond the .01 level
*** Significant beyond the .001 level

Table D IV

Intercorrelations between Ipsilateral Transmission Time and ipsilateral Half-period of Individual Brainstem Wave Components

HALF-PERIOD OF INDIVIDUAL WAVEFORMS		TRANSMISSION TIME OF INDIVIDUAL WAVEFORMS - IPSILATERAL DATA											
		I-N	I-P	II-N	II-P	III-N	III-P	IV-N	IV-P	V-N	V-P	VI-N	VI-P
I	(r)	-.345**	1.000	.521***	.431***	.496***	.306	-.107	-.128	.248	.068	.081	-.013
	(n)	66	66	51	58	65	62	21	20	66	48	36	44
II	(r)	-.223	-.140	-.292	.417**	.072	-.064	.015	-.057	.072	.306	.060	.208
	(n)	50	50	50	50	50	47	14	14	50	37	29	33
III	(r)	.264	-.383**	-.201	-.283	-.299	.315	-.226	-.252	-.211	-.379	-.039	.032
	(n)	63	62	48	55	63	63	21	20	63	45	35	42
IV	(r)	.036	-.016	.252	-.091	.111	.004	.072	.364	.395	.227	-.111	.069
	(n)	21	20	14	16	21	20	21	21	21	12	11	13
V	(r)	-.057	-.240	-.074	-.012	-.020	-.102	-.351	-.296	-.197	.710***	.223	.191
	(n)	48	48	38	42	48	45	13	12	48	48	31	36
VI	(r)	.175	-.121	-.151	-.038	.084	.111	.606	.806	-.046	-.080	-.009	.656***
	(n)	27	27	21	24	27	26	9	8	27	25	27	27

(r)= Pearson product-moment coefficient of correlation
(n) - Number of data pairs used to calculate (r)
** Significant beyond the .01 level
*** Significant beyond the .001 level

Table D V

Intercorrelations between Ipsilateral Transmission Time and Ipsilateral Peak-to-Peak Amplitude of Individual Brainstem Waves

PEAK-TO-PEAK WAVEFORM AMPLITUDE		TRANSMISSION TIME OF INDIVIDUAL WAVEFORMS - IPSILATERAL DATA											
		I-N	I-P	II-N	II-P	III-N	III-P	IV-N	IV-P	V-N	V-P	VI-N	VI-P
I	(r)	-.139	.220	.182	.248	-.136	-.113	.084	-.084	-.207	-.269	.091	-.009
	(n)	66	66	51	58	65	62	21	20	66	48	36	44
II	(r)	.071	-.207	-.227	.155	-.033	-.164	.071	-.042	.054	.190	.016	.170
	(n)	50	50	50	50	50	47	14	14	50	37	29	33
III	(r)	-.081	.068	.247	.074	-.232	-.238	.312	.185	-.360**	-.396**	.014	-.083
	(n)	63	62	48	55	63	63	21	20	63	45	35	42
IV	(r)	.104	.006	.054	-.122	-.149	-.217	.016	.248	.138	-.018	.045	.084
	(n)	21	20	14	16	21	20	21	21	21	12	11	13
V	(r)	-.000	-.009	.145	.025	-.271	-.336	-.317	-.365	-.389**	-.401**	.338	.238
	(n)	48	48	38	42	48	45	13	12	48	48	31	36
VI	(r)	.124	-.013	.051	-.100	-.137	-.023	.358	.533	-.525**	-.447	-.017	.427
	(n)	27	27	21	24	27	26	9	8	27	25	27	27

(r) = Pearson product-moment coefficient of correlation
(n) = Number of data pairs used to calculate (r)
** Significant beyond the .01 level

Table D VI

Intercorrelations between Ipsilateral Half-Period and Ipsilateral Peak-to-Peak Amplitude of Individual Brainstem Waves

HALF-PERIOD OF INDIVIDUAL WAVEFORMS		PEAK-TO-PEAK AMPLITUDE OF INDIVIDUAL WAVEFORMS - IPSILATERAL DATA					
		I	II	III	IV	V	VI
I	(r)	.220	-.207	.088	.006	-.009	-.013
	(n)	66	50	62	20	48	27
II	(r)	.118	.536***	-.140	-.059	-.122	-.180
	(n)	50	51	48	14	37	21
III	(r)	-.040	-.067	-.022	-.061	.019	.220
	(n)	62	48	66	20	47	27
IV	(r)	-.358	-.316	-.271	.786***	-.185	.234
	(n)	20	14	20	21	12	8
V	(r)	-.091	.147	-.109	-.110	-.122	-.070
	(n)	48	37	47	12	50	26
VI	(r)	-.140	.176	-.068	.320	.150	.656***
	(n)	27	21	27	8	26	28

(r) = Pearson product-moment coefficient of correlation
(n) = Number of data pairs used to calculate (r)
*** Significant beyond the .001 level

APPENDIX E

Intracorrelations between the left ear and right ear individual brainstem evoked response wave components for different ipsilateral response measurements. The data are based upon 4000-sample time-averaged responses of 35 pairs of ears to 80 dB SL acoustic click stimuli presented at a 21 Hz repetition rate.

E I. Left Ear Latency vs. Right Ear Latency
E II. Left Ear Transmission Time vs. Right Ear Transmission Time
E III. Left Ear Half-Period vs. Right Ear Half-Period
E IV. Left Ear P-P Amplitude vs. Right Ear P-P Amplitude

Table E 1

Latency Intracorrelations between the Left Ear and Right Ear Individual Brainstem Wave Components

LEFT EAR LATENCY OF INDIVIDUAL WAVEFORMS		RIGHT EAR LATENCY OF INDIVIDUAL WAVEFORMS I-N	I-P	II-N	II-P	III-N	III-P	IV-N	IV-P	V-N	V-P	VI-N	VI-P
I-N	(r)	.344	.342	.405	.395	.210	.155	.077	.106	-.053	-.122	-.419	-.187
	(n)	32	34	28	30	34	33	11	11	34	23	17	22
I-P	(r)	.335	.666***	.400	.064	.370	.353	-.279	-.367	.095	-.037	-.321	-.281
	(n)	33	34	27	29	34	33	12	12	34	24	18	22
II-N	(r)	.451	.632***	.812***	.727***	.637***	.679***	.271	.293	.193	-.100	.202	-.227
	(n)	23	24	22	22	24	23	7	7	24	17	12	16
II-P	(r)	.203	.408	.529**	.466	.433	.442	.061	.318	.231	-.307	-.318	-.466
	(n)	28	29	25	26	29	28	8	8	29	22	15	20
III-N	(r)	.288	.209	.424	.375	.736***	.691***	.391	.327	.561***	.271	-.225	-.200
	(n)	32	34	28	29	34	33	12	12	34	24	18	23
III-P	(r)	.190	.264	.339	.330	.778***	.653***	-.031	-.032	.582***	.487	-.199	-.245
	(n)	30	32	26	27	32	32	11	11	32	22	18	22
IV-N	(r)	.226	.545	.690	.546	.618	.510	.965**	.900	.167	-.251	NC	-.366
	(n)	9	10	8	8	10	10	5	5	10	6	4	7
IV-P	(r)	.228	.446	.702	.672	.671	.497	.987**	.913	.143	.015	NC	-.144
	(n)	8	9	7	7	9	9	5	5	9	5	3	6
V-N	(r)	.348	.355	.427	.321	.579***	.470**	.147	.213	.756***	.362	-.241	-.265
	(n)	33	35	28	30	35	34	12	12	35	24	18	23
V-P	(r)	-.114	-.139	.122	.230	.269	.075	-.334	-.288	.456	.463	.133	-.076
	(n)	25	26	21	22	26	25	8	8	26	21	15	18
VI-N	(r)	.161	.087	.043	.042	-.111	-.250	NC	NC	.086	.467	.683	.037
	(n)	18	19	14	14	19	19	4	4	19	16	11	13
VI-P	(r)	.367	-.083	.350	.231	.084	.048	-.117	-.194	.226	.230	.541	.032
	(n)	23	25	19	20	25	24	9	9	25	17	13	18

(r) = Pearson product-moment coefficient of correlation
(n) = Number of data pairs used to calculate (r)
** Significant beyond the .01 level
*** Significant beyond the .001 level

NC = Not Calculated, n < 5

Table E II

Transmission Time Intercorrelations between the Left Ear and Right Ear Individual Brainstem Wave Components

LEFT EAR TRANSMISSION TIME OF INDIVIDUAL WAVEFORMS		RIGHT EAR TRANSMISSION TIME OF INDIVIDUAL WAVEFORMS I-N	I-P	II-N	II-P	III-N	III-P	IV-N	IV-P	V-N	V-P	VI-N	VI-P
I-N	(r)	.344	.151	.093	.051	.039	-.008	-.142	-.138	-.209	-.242	-.490	-.179
	(n)	32	32	27	29	32	31	11	11	32	22	17	20
I-P	(r)	.184	.256	.001	-.258	.010	.064	-.281	-.380	-.018	-.112	-.194	-.368
	(n)	32	32	27	29	32	31	11	11	32	22	17	20
II-N	(r)	.270	.116	.478	.193	.152	.291	.390	.304	-.076	-.155	.478	-.355
	(n)	23	23	22	22	23	22	7	7	23	16	12	15
II-P	(r)	.042	.196	.287	.123	.256	.302	.022	.202	.237	-.165	-.160	-.462
	(n)	28	28	25	26	28	27	8	8	28	21	15	19
III-N	(r)	.106	-.140	.088	-.025	.460**	.493**	.510	.432	.507**	.294	-.033	-.201
	(n)	31	31	27	28	31	30	11	11	31	22	17	20
III-P	(r)	.030	-.010	.180	.100	.622***	.561***	.377	.415	.597***	.541	-.055	-.273
	(n)	29	29	25	26	29	29	10	10	29	20	17	19
IV-N	(r)	.123	.432	.429	-.019	.320	.249	.627	.471	.294	-.235	NC	-.512
	(n)	9	9	7	7	9	9	5	5	9	6	4	6
IV-P	(r)	.125	.382	.386	.032	.400	.276	.802	.617	.275	.083	NC	-.112
	(n)	8	8	6	6	8	8	5	5	8	5	3	5
V-N	(r)	.195	.007	.016	-.087	.322	.305	-.034	.009	.691***	.334	-.158	-.270
	(n)	32	32	27	29	32	31	11	11	32	22	17	20
V-P	(r)	-.208	-.105	.101	.157	.397	.306	.269	.352	.619**	.518	.102	-.171
	(n)	24	24	21	22	24	23	7	7	24	19	14	16
VI-N	(r)	.085	-.014	.014	.051	-.180	-.373	NC	NC	.029	.395	.765**	.230
	(n)	17	17	14	14	17	17	3	3	17	14	10	11
VI-P	(r)	.286	-.318	-.053	-.207	.039	.042	-.106	-.204	.177	.078	.485	.223
	(n)	22	22	18	19	22	21	8	8	22	15	12	15

(r) = Pearson product-moment coefficient of correlation

(n) = Number of data pairs used to calculate (r)

** Significant beyond the .01 level

*** Significant beyond the .001 level

NC = Not Calculated, n < 5

Table E III

Half-Period Intracorrelations between the Left Ear and Right Ear Individual Brainstem Waves

LEFT EAR HALF-PERIOD OF INDIVIDUAL WAVEFORMS		RIGHT EAR HALF-PERIOD OF INDIVIDUAL WAVEFORMS I	II	III	IV	V	VI
I	(r)	.256	-.453	.058	-.212	-.225	-.217
	(n)	32	27	32	11	23	12
II	(r)	.111	.370	-.033	.574	.059	.488
	(n)	22	21	22	6	17	8
III	(r)	.096	.065	-.278	.268	.412	-.307
	(n)	30	26	32	11	22	13
IV	(r)	.244	-.066	-.625	-.649	-.243	NC
	(n)	8	7	9	5	5	2
V	(r)	.014	.190	-.186	.488	.376	-.157
	(n)	25	21	25	8	21	11
VI	(r)	-.188	-.319	-.022	NC	-.195	.876
	(n)	14	10	15	4	12	6

(r) = Pearson product-moment coefficient of correlation

(n) = Number of data pairs used to calculate (r)

NC = Not Calculated, $n < 5$

Table E IV

Peak-to-Peak Amplitude Intracorrelations between the Left Ear and Right Ear Individual Brainstem Waves

LEFT EAR PEAK-TO-PEAK WAVEFORM AMPLITUDE		RIGHT EAR PEAK-TO-PEAK AMPLITUDE OF INDIVIDUAL WAVEFORMS I	II	III	IV	V	VI
I	(r)	.501**	-.069	.375	.165	.258	.249
	(n)	32	27	32	11	23	12
II	(r)	-.002	.218	.069	.118	-.014	.361
	(n)	22	21	22	6	17	8
III	(r)	.488**	.253	.797***	-.112	.444	.385
	(n)	30	26	32	11	22	13
IV	(r)	-.729	-.431	.321	-.578	.162	NC
	(n)	8	7	9	5	5	2
V	(r)	.086	.045	.578**	-.257	.913***	.259
	(n)	25	21	25	8	21	11
VI	(r)	.273	.099	.185	NC	.479	.908
	(n)	14	10	15	4	12	6

(r) = Pearson product-moment coefficient of correlation
(n) = Number of data pairs used to calculate (r)
** Significant beyond the .01 level
*** Significant beyond the .001 level

NC = Not Calculated, $n < 5$

APPENDIX F

tracorrelations between the ipsilateral ear and contralateral ear individual brain-m evoked response wave components for different response measurements. The data e based upon 4000-sample time-averaged responses of 70 ears to 80 dB SL acoustic ick stimuli presented at a 21 Hz repetition rate.

F I. Ipsi Ear Latency vs. Contra Ear Latency
F II. Ipsi Ear Transmission Time vs. Contra Ear Transmission Time
F III. Ipsi Ear Half-Period vs. Contra Ear Half-Period
F IV. Ipsi Ear P-P Amplitude vs. Contra Ear P-P Amplitude

Table F 1

Latency Intracorrelations between the Ipsilateral and Contralateral Brainstem Wave Components

IPSILATERAL EAR LATENCY OF INDIVIDUAL WAVEFORMS		CONTRALATERAL EAR LATENCY OF INDIVIDUAL WAVEFORMS											
		I-N	I-P	II-N	II-P	III-N	III-P	IV-N	IV-P	V-N	V-P	VI-N	VI-P
I-N	(r)	.377	.241	.153	.031	.330	.133	.421**	.362	.265	.294	.135	.189
	(n)	12	55	32	33	46	64	39	39	66	39	28	33
I-P	(r)	.579	.366**	.350	.308	.369	.294	.420**	.426**	.284	.086	-.018	.019
	(n)	13	56	33	34	47	66	40	40	68	41	29	34
II-N	(r)	.649	.414**	.718***	.544**	.694***	.573***	.706***	.726***	.373**	.072	.144	.099
	(n)	11	45	31	28	34	49	30	29	52	29	20	26
II-P	(r)	.749**	.361	.595***	.731***	.552***	.619***	.638***	.633***	.374**	.047	-.033	.066
	(n)	11	49	31	30	39	56	33	33	59	34	25	32
III-N	(r)	.378	.379**	.597***	.641***	.853***	.814***	.735***	.745***	.688***	.230	.339	-.041
	(n)	13	56	32	33	46	66	40	40	69	42	30	34
III-P	(r)	.500	.396**	.558**	.524**	.761***	.723***	.664***	.627***	.576***	.104	.240	.049
	(n)	13	53	29	31	44	64	39	39	66	41	29	33
IV-N	(r)	NC	.261	.716	.465	.494	.398	.774***	.872***	.354	.350	.473	.017
	(n)	2	19	10	12	16	21	17	16	22	12	9	10
IV-P	(r)	NC	.332	.762	.274	.599	.330	.788***	.90[illegible]***	.408	.526	.556	-.193
	(n)	1	18	10	11	15	20	16	15	21	11	8	10
V-N	(r)	.024	.279	.270	.403	.621***	.584***	.388	.582***	.799***	.490***	.122	.136
	(n)	13	57	33	34	47	67	40	40	69	42	30	34
V-P	(r)	.189	.200	.112	.413	.345	.352	.009	.070	.593***	.804***	.528**	.453
	(n)	10	39	25	22	34	47	31	31	50	33	26	23
VI-N	(r)	-.425	.070	.202	-.085	-.233	-.021	-.374	-.305	.030	.218	.469	.105
	(n)	9	31	19	18	25	35	24	23	37	24	20	21
VI-P	(r)	.062	.027	.192	.032	-.015	.083	-.152	-.181	.117	.303	.323	.005
	(n)	9	41	22	21	32	46	28	27	48	31	24	26

(r) = Pearson product-moment coefficient of correlation
(n) = Number of data pairs used to calculate (r)
** = Significant beyond the .01 level
*** = Significant beyond the .001 level

NC = Not Calculated, n < 5

Table F II

Transmission Time Intercorrelations between the Ipsilateral and Contralateral Brainstem Wave Components

IPSILATERAL EAR TRANSMISSION TIME OF INDIVIDUAL WAVEFORMS		CONTRALATERAL EAR TRANSMISSION TIME OF INDIVIDUAL WAVEFORMS											
		I-N	I-P	II-N	II-P	III-N	III-P	IV-N	IV-P	V-N	V-P	VI-N	VI-P
I-N	(r)	.377	.606	-.144	-.068	.128	.059	.056	-.058	-.052	-.111	.045	.082
	(n)	12	12	9	11	10	12	9	9	12	10	6	5
I-P	(r)	.501	-.367	.568	.150	.191	.198	.162	.345	.034	-.077	.403	.906
	(n)	12	12	9	11	10	12	9	9	12	10	6	5
II-N	(r)	.298	-.538	.586	.249	.209	.194	.229	.263	.077	-.057	NC	.917
	(n)	10	10	9	10	8	10	7	7	10	8	4	5
II-P	(r)	.393	.017	-.179	.043	-.232	.144	.082	.320	-.021	-.237	.044	.463
	(n)	10	10	8	10	8	10	7	7	10	9	5	5
III-N	(r)	.150	-.560	.563	.498	.366	.442	-.204	.256	.540	.307	.138	.179
	(n)	12	12	9	11	10	12	9	9	12	10	6	5
III-P	(r)	.367	-.383	.281	.274	.101	.240	-.159	.154	.470	-.146	.200	-.000
	(n)	12	12	9	11	10	12	9	9	12	10	6	5
IV-N	(r)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(n)	2	2	1	2	2	2	2	2	2	2	2	NC
IV-P	(r)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	(n)	1	1	1	1	1	1	1	1	1	1	1	NC
V-N	(r)	-.133	-.303	.828**	.863***	.546	.838***	.403	.787	.873***	.509	.520	.323
	(n)	12	12	9	11	10	12	9	9	12	10	6	5
V-P	(r)	.091	-.470	.334	.252	.090	.235	-.122	.152	.398	.702	.500	NC
	(n)	10	10	7	9	9	10	8	8	10	8	6	4
VI-N	(r)	-.508	.207	-.316	-.110	-.571	-.145	.048	-.095	-.272	.352	.037	NC
	(n)	9	9	6	8	8	9	7	7	9	8	6	4
VI-P	(r)	-.093	-.628	-.071	-.013	-.368	-.307	-.527	-.657	-.105	.187	NC	NC
	(n)	8	8	6	8	6	8	6	6	8	7	4	4

(r) = Pearson product-moment coefficient of correlation
(n) = Number of data pairs used to calculate (r)
** Significant beyond the .01 level
*** Significant beyond the .001 level

NC = Not Calculated, n < 5

Table F III

Half-Period Intracorrelations between the Ipsilateral and Contralateral Brainstem Waves

IPSILATERAL EAR HALF-PERIOD OF INDIVIDUAL WAVEFORMS		CONTRALATERAL EAR HALF-PERIOD OF INDIVIDUAL WAVEFORMS					
		I	II	III	IV	V	VI
I	(r)	-.367	-.524**	.075	.375	-.390	-.068
	(n)	12	25	46	35	38	16
II	(r)	-.026	.441	-.053	-.245	-.124	-.349
	(n)	10	22	33	26	29	12
III	(r)	.204	.054	.075	-.155	-.220	.103
	(n)	13	22	44	35	41	17
IV	(r)	NC	-.677	-.580	.455	.242	NC
	(n)	1	8	15	15	11	4
V	(r)	-.512	-.141	-.038	-.142	.687***	.363
	(n)	10	18	34	28	33	14
VI	(r)	.448	.192	.103	-.217	.225	-.108
	(n)	5	8	19	16	19	10

(r) = Pearson product-moment coefficient of correlation
(n) = Number of data pairs used to calculate (r)
** Significant beyond the .01 level
*** Significant beyond the .001 level

NC = Not Calculated, n < 5

Table F IV

Peak-to-Peak Amplitude Intracorrelations between the Ipsilateral and Contralateral Brainstem Waves

IPSILATERAL EAR PEAK-TO-PEAK WAVEFORM AMPLITUDE		CONTRALATERAL EAR PEAK-TO-PEAK AMPLITUDE OF INDIVIDUAL WAVEFORMS					
		I	II	III	IV	V	VI
I	(r)	.285	.046	.456**	.319	.274	.600
	(n)	12	25	46	35	38	16
II	(r)	.271	.429	-.043	-.048	-.257	-.324
	(n)	10	22	33	26	29	12
III	(r)	-.154	-.265	.899***	.214	.432	.250
	(n)	13	22	44	35	41	17
IV	(r)	NC	.325	-.161	.276	.256	NC
	(n)	1	8	15	15	11	4
V	(r)	.215	-.640**	.515**	.196	.375	.200
	(n)	10	18	34	28	33	14
VI	(r)	.843	-.378	.190	.138	.373	.589
	(n)	5	8	19	16	19	10

(r) = Pearson product-moment coefficient of correlation
(n) = Number of data pairs used to calculate (r)
** Significant beyond the .01 level
*** significant beyond the .001 level

NC = Not Calculated, n < 5

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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Bioinstrumentation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Brainstem auditory evoked response data based upon simultaneous ipsilateral and contralateral recordings have been collected and analysed for a selected population (age 20 to 24 years) of naval aviation students. An extensive set of statistical tables is provided for both forms of recordings which establishes the normative range of brainstem responses for this population, using acoustic click stimuli with a 21-Hz repetition

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NAMRL-1262. Pensacola, FL: Naval Aerospace Medical Research Laboratory, 7 August.

Brainstem auditory evoked response data based upon simultaneous ipsilateral and contralateral recordings have been collected and analyzed for a selected population (age 20-25 years) of naval aviation students. A set of statistical tables establishes normative ranges for the latency, transmission time, half-period, and peak-to-peak amplitude of brainstem Waves I through VI for both forms of recordings. The measures derive from acoustic click stimuli presented repetitively at a 21-Hz rate and at levels 40, 60, and 80 dB above sensory threshold. Latency and amplitude differences observed between the ipsilateral and contralateral responses for certain waves are described in detail. A set of correlation matrices is included to describe the relationships that exist among the brainstem waves and the four brainstem measurement parameters.

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